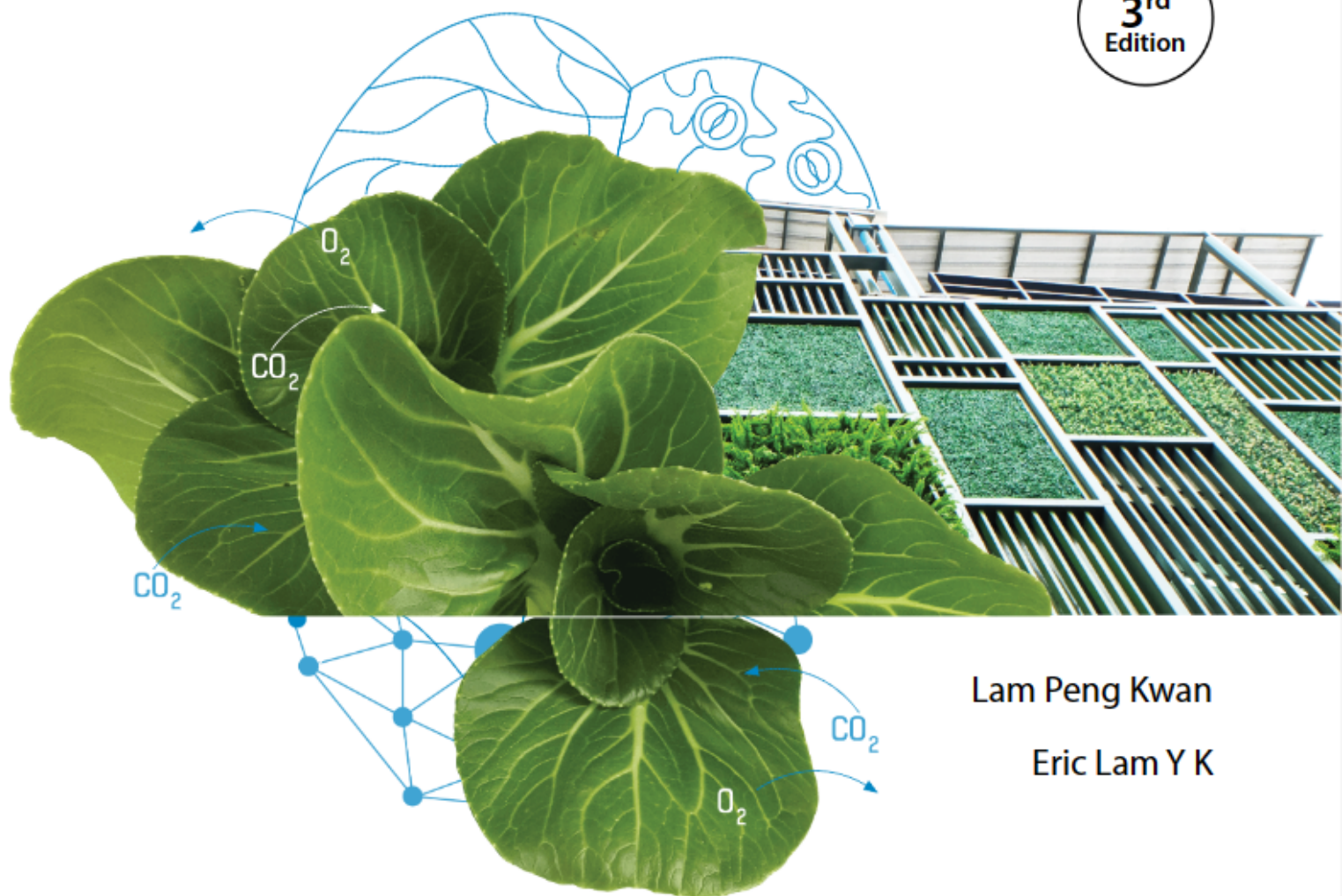


BIOLOGY

MATTERS

GCE 'O' Level
Textbook

3rd
Edition



Lam Peng Kwan
Eric Lam Y K

About the Biology Matters Author Team

Lam Peng Kwan

Lam Peng Kwan has more than 40 years of experience teaching Biology at secondary and junior college levels. He was the first prize winner of the Creative Science Teachers' Award at a competition on Classroom Teaching for Secondary Schools and Junior Colleges, organised by the Science Council of Singapore and Science Teachers' Association of Singapore. With over 40 years of writing experience, Lam Peng Kwan has authored several Biology textbooks and workbooks, including co-authoring an instructional package for IGCSE Biology. He was also a specialist writer in Biology for the Curriculum Development Institute of Singapore.



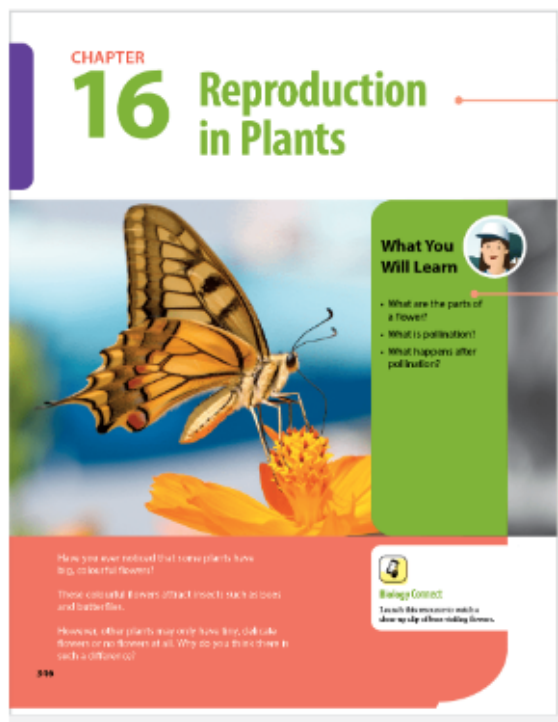
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Eric Lam Y K graduated from the National University of Singapore with First Class Honours in Molecular Biology. An internationally recognised expert in STEM learning, inquiry-based pedagogies, formative assessments and eLearning, Eric pioneered an award-winning method of inquiry-based teaching using interactive technologies. His works in combining interactive digital media and pedagogy have been endorsed by world-renowned experts in science education and assessment. He also regularly shares his expertise in Education Technology in professional conferences and roundtables. Eric has co-authored Biology textbooks and workbooks, which formed the base text for schools for more than 20 years. He has also co-authored an instructional package for IGCSE Biology.



About This Book

The **Biology Matters for GCE 'O' Level Textbook (3rd Edition)** is aligned with the latest GCE 'O' Level Biology syllabus by the Ministry of Education. Designed for effective concept development and reinforcement, the Textbook includes tasks and activities at appropriate junctures for students to apply their critical and creative thinking skills. Real-life contexts, infographics and integrated videos and simulations are used to enhance learning and make Biology come alive.



Chapter Opener introduces the topic with engaging real-life contexts and trigger questions.

What You Will Learn provides an overview of the sections to be covered in the chapter in the form of inquiry questions

Learning Outcomes list the learning objectives at the start of each section to keep students focused.

Biology Connect allows students to scan the QR codes to access complimentary digital resources* such as videos and simulations that are interesting and informative, making science truly come alive.

* The digital resources used in Biology Connect have not been reviewed or endorsed by the Singapore Ministry of Education.



Chapter 12 | Living Together – Plants, Animals and Ecosystems

12.3 What Is Photosynthesis?

Learning Outcomes

- State that chlorophyll absorbs light energy and converts it into chemical energy for the formation of carbohydrates and their subsequent use.
- Explain why most forms of life are completely dependent on photosynthesis.
- State the equations, in words and symbols, for photosynthesis.
- Investigate and discuss the effects of varying light intensity, carbon dioxide concentration and temperature on the rate of photosynthesis.
- Classify light intensity, carbon dioxide concentration and temperature as limiting factors in the rate of photosynthesis.

Humans and other animals need to eat to survive. However, have you ever seen a plant 'eat'? Unlike them, some common plants that trap and digest insects, and plants that eat soil in the same that animals do. Do plants get 'hungry'? How do they 'eat'?

In order to perform the various vital functions of the body, a living organism must be provided with sufficient energy. This energy is obtained from breaking down energy-rich organic molecules in food. But where does the energy in food come from? We will discuss this in this section.

Imagine that you had coffee, bread and a hard-boiled egg for breakfast (Figure 12.2). Where did the organic molecules in each of these foods come from?

If you trace these organic molecules back to their origin, you will realise that they come, directly or indirectly, from plants.



Figure 12.2 Where organic molecules come from

Infographics and stepwise presentations help students visualise abstract concepts and break down difficult concepts into bite-sized information that is easy to understand.

About This Book

Link <forward/backward> shows connections across chapters and sections by linking back to students' prior learning and linking forward to prepare them for related chapters they will learn later.

Tech Connect showcases cutting-edge technology used for the benefit of life, society and the environment.

Worked Example guides students on how to interpret a question and work out the solution.

Concept Cartoon challenges students' ideas, triggers discussions and aids in clearing misconceptions.

Let's Practise prompts immediate checks on understanding at the end of the section and facilitates the reinforcement of key concepts.

Link <to Physics/Chemistry> allows students to appreciate the interconnectedness of concepts among the various science subjects.

Helpful Note highlights misconceptions, tips and additional information to support students' learning.

Chapter 18 | Continuity of Life



Link
Blood type has an effect on the function of blood, which is the function of blood.

An individual can only have two alleles, one allele from each parent. With multiple alleles, there can be different combinations of the two alleles. This makes it possible to have more than two phenotypes expressed based on the dominant or recessive alleles available in the trait.

Allele	Genotype
A	AA or Aa
B	BB or Bb
AB	AB
O	OO

The gene for human blood group is an example of a gene with multiple alleles. There are four blood groups in human populations, namely A, B, AB and O. The alleles for blood groups A, B and O are designated as P, P and P respectively. P and P are dominant over O, but P and P co-dominance. Therefore, individuals with alleles P and P have the blood group AB. The blood groups and their respective genotypes are shown in Table 18.2.

Worked Example 18C

A man of blood group A is mated to a woman of blood group B. They have a child whose blood group is O.

- (a) Explain, by means of a genetic diagram, how it is possible for the couple to have a child with blood group O.
(b) What is the probability that their next child will have blood group O?

Solution

Let P, P and P be the alleles for blood group A, B and O respectively. P and P are dominant over O, and P and P are co-dominant, and together will give AB blood group.

(a) For a child to have blood group O, the child must have the genotype OO. This means both his parents must have one P allele. His father's genotype must be PP and his mother's genotype PP (Figure 18.2).

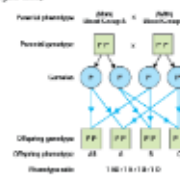


Figure 18.2

- (b) The probability that the next child will have blood group O is 1/4 or 25%.



Link
Study: Workbook, Unit 18C

296

Chapter 12 | Living Together – Plants, Animals and Ecosystems



Figure 12.21 In commercial greenhouses, the temperature can be controlled, and more carbon dioxide can be added to the air to make plant growth faster. There is always plenty of light.



Tech Connect
Green plants have the ability to convert solar energy into stored chemical energy. This is done against every obstacle and against the design of the plant that can harness energy from the sun (Figure 12.22). The process of photosynthesis is still a mystery to scientists, but it is the process that provides the basis for the food chain.

The solar panel generator is a small device that converts light energy into electrical energy. It is made of silicon cells. These cells are able to convert a considerable amount of energy and can be used to power a small house or even a city. In this way, the solar panel generator is a small-scale version of the solar panel that can be used to power a city.

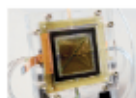


Figure 12.22 A solar panel generator that converts light energy into electrical energy.

What Are the Limiting Factors in Photosynthesis?

Study Figure 12.20. Initially, as the light intensity increases, the rate of photosynthesis increases. From 0 to A, light intensity is the limiting factor. A limiting factor is any factor that directly affects the rate of a chemical reaction. The rate of the reaction can be increased only if the value of the limiting factor is increased.

Beyond point A, light is no longer the limiting factor since the rate of photosynthesis remains constant even though the light intensity increases. Some other factor, possibly temperature or carbon dioxide concentration, becomes the limiting factor that causes the leveling off of the graph at point AB.

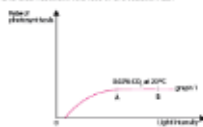


Figure 12.20 Effect of increasing light intensity on the rate of photosynthesis at 20°C



Link
We have that rate of reaction are affected by concentration, pressure, particle size and temperature.

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Chapter 11 | The Human Body – Maintaining Life

Look at Figure 11.4. Give your views on the statements made about wearing masks during an outbreak of an infectious disease, such as COVID-19.



Figure 11.4 Three statements in discussing whether masks should be worn during an outbreak of an infectious disease, such as COVID-19. Give your view on why or why not?



Helpful Note

Figure 11.4 shows how people of different ages can spread the disease.

Wearing masks is a key strategy in the spread of disease (Figure 11.4). Masks can help reduce the likelihood and severity of transmission by blocking the release of pathogens from the mouth and nose. The key to reducing the spread of disease is to prevent the release of pathogens from the mouth and nose. Wearing masks, avoiding crowded places, and avoiding contact with people who are sick are all ways to reduce the spread of disease.



Figure 11.4 shows how people of different ages can spread the disease. Wearing masks is a key strategy in the spread of disease (Figure 11.4). Masks can help reduce the likelihood and severity of transmission by blocking the release of pathogens from the mouth and nose. The key to reducing the spread of disease is to prevent the release of pathogens from the mouth and nose. Wearing masks, avoiding crowded places, and avoiding contact with people who are sick are all ways to reduce the spread of disease.



Link
Practical: Workbook, Experiment 11A

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12.4 How Can We Study the Movement of Substances in Plants?

Learning Outcome

- Define the term *translocation* as the transport of food (mainly sucrose) in the phloem tissue and illustrate the process through translocation studies.

Animals have a circulatory system that moves blood around their bodies in order to transport substances. Plants also have a way of moving water and dissolved substances around their bodies. With animals, we can measure pulses, but plants have no heartbeat. How then can we study the movement of water and food substances in plants?

How Can We Study the Path Water Takes Through a Plant?

Let's Investigate 12.10

Aim

To investigate the path of water through a plant.

Procedure

1. Take a celery plant and wash it with water to remove the soil. A celery stem may be used for this experiment.
2. Allow the plant to stand with its stem immersed in methylene blue (or dilute red ink) solution (Figure 12.43).
3. After a few hours, you can see that the blue dye has risen up the stem. Cut it in two reverse sections of the stem.
4. Place the sections on a glass slide. Examine the sections under a light microscope.
5. Sketch the transverse section of the stem to show the distribution of the blue colour (methylene blue) in the main vein or the vascular bundle.

Observation and Conclusion

1. Which tissue has been stained blue?
2. What conclusion can you draw from your investigation?

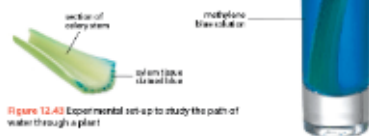


Figure 12.43 Experimental set-up to study the path of water through a plant.



Disciplinary Idea

Systems
The plants transport system moves food to leaves through sufficient raw materials for photosynthesis and that the whole plant subsequently receives the products of photosynthesis for growth.



Link
Practical Workbook
Experiment 12G

265

Let's Investigate reinforces concepts through investigative procedures or hands-on activities.

Link <to Theory Workbook /Practical Workbook> allows for seamless learning and reinforcement of concepts across the Textbook, Theory Workbook and Practical Workbook.

Problem-based Learning Activity hones problem-solving skills by encouraging students to develop solutions to a real-life problem.

Cool Career showcases a career related to the topic to inspire students and show them the relevance of science in the workplace.

Disciplinary Ideas highlight the overarching ideas of Biology that can be applied to explain real-life problems or phenomena. The Disciplinary Ideas include:

- **The Cell** — Diverse life forms are similar in that their basic unit are cells.
- **Structure and Function** — Structure and function of organisms from the molecular to the organ system levels are related to each other.
- **Systems** — Biological systems interact among themselves and with the environment resulting in the flow of energy and nutrients.
- **Energy** — To ensure survival, living organisms obtain, transform and utilise energy from the external world.
- **Homeostasis, Co-ordination and Response** — Living organisms detect changes both from the surrounding environment and within themselves so that they are able to respond to these changes to maintain a constant internal environment needed for sustaining life.
- **Heredity** — Genetic information is passed on from parents to offspring during reproduction to ensure the continuity of life.
- **Evolution** — The diversity of living organisms is achieved through a process of evolution, driven by mechanisms such as natural selection.

Problem-based Learning Activity

It is the month of December in Singapore. Many people are suffering from the flu, caused by a seasonal strain of the influenza virus. The flu season that has just started seems more serious than any of the flu seasons we have seen in the past. The reason being that this particular virus spreads three times as quickly. The number of the related deaths is also higher than in previous years. In a situation like this, scientists often race against time to develop treatment options (Figure 11.21).

The Ministry of Health has called together a team of experts to study the problem. As a member of the expert team, you are tasked to suggest ways to slow down the spread of the virus. Apply what you know about the influenza virus and how it infects the human body to design ways to solve this problem.

- Consider the following questions:
- What virus are you concerned together for this task and how would you do it?
 - What are the best treatment options? What are some ways to prevent contraction or spread of the virus?
 - What recent technologies or innovations are you aware of that can help manage the spread of infection?

Figure 11.21 Scientists must constantly monitor and come up with new medicines and treatment options for infectious diseases.



Cool Career

Epidemiologist

Have you ever heard about real diseases outbreak? The scientist, influenza study, is called an epidemiologist. They study the spread of diseases in communities (Figure 11.22). They help identify a disease, determine its cause, and prevent or control the spread of infection. They work in a variety of ways such as environmental health, infectious diseases, chronic diseases and outbreaks. Working as an epidemiologist, you will be involved in many ways around the world to monitor the health of the population and use statistical analysis to find out how specific diseases are transmitted and spread.

Typically, an epidemiologist has no interest in research and investigation. He or she is more on social challenges with an open and objective mindset. This means in the public health sector, they require epidemiologists to communicate effectively with other health professionals and the wider community.

Figure 11.22 Epidemiologist holding a potential infectious blood sample



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About This Book

Chapter 6 | The Human Body – Maintaining Life



Past to Present

Heart disease is a modern medical issue. Evidence of heart disease is negligible even in the most ancient civilisations (Figure 6.42). Right up to the 19th century, there were no reliable treatments, and evidence indicates that had some effective patients. Modern heart disease is considered one of the top medical causes of death in some countries. There is evidence to suggest that the cardiovascular system was not fully developed in the body. There was also evidence that some ancient civilisations, such as the Egyptians, had a better understanding of the heart than we do today. Some ancient civilisations, such as the Egyptians, had a better understanding of the heart than we do today. Some ancient civilisations, such as the Egyptians, had a better understanding of the heart than we do today.



Figure 6.42 Plaster: Rembrandt (1635) *Old man with a heart disease*

What Can We Do to Reduce the Risk of Getting Coronary Heart Disease?

The following are ways to reduce the risk of getting coronary heart disease:

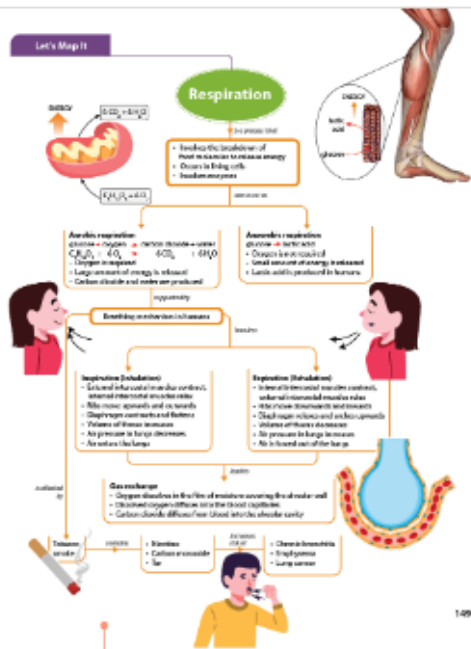
- A healthy diet is important in reducing the risk of coronary heart disease. Diet is one of the most important factors in preventing coronary heart disease. A diet that is high in saturated fats, cholesterol, and sodium can increase the risk of getting coronary heart disease. A diet that is low in saturated fats, cholesterol, and sodium can reduce the risk of getting coronary heart disease.
- Regular physical exercise has long been beneficial effects on the cardiovascular system. It strengthens the heart and makes it more efficient. Regular physical exercise has long been beneficial effects on the cardiovascular system. It strengthens the heart and makes it more efficient.
- The risk of high blood pressure or hypertension can be greatly reduced.



Past to Present inspires the spirit of scientific inquiry through examples of scientific innovation and the evolution of scientific developments over time, demonstrating the nature of science.

Respiration in Humans | Chapter 7

Let's Map It



Let's Map It summarises the relationships among key concepts in the chapter through a visual concept map.



Let's Review

Now do a 10-minute quiz to test your understanding of Chapter 6.



Word Alert

Now do a 10-minute quiz to test your understanding of Chapter 6.

Breathing and life are closely connected in many languages, the same word is used for 'breathe' and 'live'. Use a dictionary to check for breathing to determine if someone is still alive. If you try to hold your breath, after a certain time, your body fights to breathe again. Your body is programmed to keep breathing. Why is breathing so important?

How Do Organisms Take In Oxygen for Aerobic Respiration?

Organisms take in oxygen for aerobic respiration through the process of gas exchange.

Gas exchange is the exchange of gases between an organism and the environment.

Unilateral organisms, such as a fish, have a large surface area-to-volume ratio. Such organisms do not require any special gas exchange system or organ to transport molecules. Oxygen and carbon dioxide can be exchanged efficiently between the organism and the environment, such as the gills of a fish, through the cell membrane.



Figure 7.2 Gas exchange and gas exchange in fish

Large animals, such as humans, have a small surface area-to-volume ratio. Their surface area is not sufficient to exchange gases efficiently. They have a special gas exchange system or organ to transport molecules. Oxygen and carbon dioxide can be exchanged efficiently between the organism and the environment, such as the lungs of a human, through the cell membrane.

In humans, the absorption of oxygen in the lungs and the removal of carbon dioxide from the body occur in the alveoli (see end of the chapter).

The Human Gas Exchange System

The human gas exchange system is shown in Figure 7.6 on the next page. It includes the trachea, the bronchi, and the alveoli leading to them. The air passage consists of the trachea, bronchi, bronchioles, and alveoli. The trachea, bronchi, bronchioles, and alveoli are also vital parts of the gas exchange system, and their functions will be discussed in Section 7.2, which covers the breathing mechanism in humans.

Word Alert provides language support by explaining certain difficult words in context or giving information on word forms.

Chapter 6 | The Human Body – Maintaining Life

Let's Review

Section A: Multiple-choice Questions
From section 6.1 and answer questions 1–5.

Figure 6.42 shows the pressure changes in the left side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.43 shows the pressure changes in the right side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.44 shows the pressure changes in the left side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.45 shows the pressure changes in the right side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.46 shows the pressure changes in the left side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.47 shows the pressure changes in the right side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.48 shows the pressure changes in the left side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.49 shows the pressure changes in the right side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.50 shows the pressure changes in the left side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.51 shows the pressure changes in the right side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.52 shows the pressure changes in the left side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.53 shows the pressure changes in the right side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.54 shows the pressure changes in the left side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.55 shows the pressure changes in the right side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.56 shows the pressure changes in the left side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.57 shows the pressure changes in the right side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.58 shows the pressure changes in the left side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.59 shows the pressure changes in the right side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.60 shows the pressure changes in the left side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.61 shows the pressure changes in the right side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.62 shows the pressure changes in the left side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.63 shows the pressure changes in the right side of the heart. With reference to the graph, answer questions 1–5.

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Figure 6.66 shows the pressure changes in the left side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.67 shows the pressure changes in the right side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.68 shows the pressure changes in the left side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.69 shows the pressure changes in the right side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.70 shows the pressure changes in the left side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.71 shows the pressure changes in the right side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.72 shows the pressure changes in the left side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.73 shows the pressure changes in the right side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.74 shows the pressure changes in the left side of the heart. With reference to the graph, answer questions 1–5.

Figure 6.75 shows the pressure changes in the right side of the heart. With reference to the graph, answer questions 1–5.

The following features are also included at the end of the book:

Answer Key lists the answers to Let's Practise, Let's Investigate and Let's Review.

Quick Revision Guide consolidates key definitions and concepts at the back of the book for easy revision.

Index provides a list of key words with page reference for easy searching.

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* Chapters with Problem-based Learning Activity

CHAPTER

01

Cell Structure and Organisation



LAB-GROWN
CHICKEN



LAB-MEAT-6933

CULTURED MEAT

Meat produced by in vitro cell
culture of animal cells.

| CRUELTY FREE | SAFE | HEALTHY |
| ENVIRONMENTALLY FRIENDLY |

Eat meat with a clear conscience.

NET WT. 17OZ (482g)

What You Will Learn



- What are cells?
- How are cells adapted to their functions?

In December 2020, the Singapore government approved the sale of the world's first chicken meat that did not come from the slaughtering of chickens. The chicken meat is grown in the laboratory from animal muscle cells.



For the first time in history, our knowledge of cell biology has enabled humans to enjoy consuming meat without having to kill any animals!

1.1 What Are Cells?

Learning Outcomes

- Identify and state the functions of the following cell structures (including organelles) of typical plant and animal cells from diagrams, light micrographs and as seen under the light microscope using prepared slides and fresh material treated with an appropriate temporary staining technique: cell wall, cell membrane, cytoplasm, nucleus, cell vacuoles (large, sap-filled in plant cells, small, temporary in animal cells), chloroplasts.
- Identify and state the functions of the following membrane systems and organelles from diagrams and electron micrographs: endoplasmic reticulum, Golgi body, mitochondria, ribosomes.
- Compare the structure of typical animal and plant cells.

Imagining Cells as Chemical Factories

All living things are made up of billions of tiny cells, just as a building is made of bricks. *Cells are the building blocks of life. They are the simplest structural and functional units of life.*

What do you think cells do? To answer this question, you need to imagine your cells as chemical factories. Many chemical reactions occur continually inside these factories to keep you alive. For example:

- A cell takes in raw materials.
- Then, it processes these materials to make new molecules.
- These molecules can either be used by the cell itself or transported to other parts of the body.

In any factory, there are different departments that carry out different functions. A cell also has different structures that perform different roles within the cell. For example, mitochondria provide energy for cell activities, and chloroplasts carry out photosynthesis. Such division of labour increases efficiency within the system. It ensures that the cell can survive and perform its role within the body.

How Did Cells Get Their Name?

The term 'cells' was first introduced by an English scientist, Robert Hooke, in 1667. He used one of the earliest microscopes to examine thin slices of cork from the bark of a tree (Figure 1.1). Hooke saw closely packed little boxes with thick walls. He named the boxes 'cells', just like the cells in a honeycomb or a prison. In fact, Hooke only saw the walls of dead plant cells.

Figure 1.1 Robert Hooke observed that cork is made up of tiny cells.



How Can We Study the Parts of the Cell?

Most cells are too small to be seen with our eyes alone. We can use light and electron microscopes to help us to see cells and their parts. Over 300 years ago, biologists like Robert Hooke and Antonie van Leeuwenhoek created their own light microscopes to study microscopic objects!

- **Light microscopes** magnify objects up to 1000x (spoken: one thousand times) (Figure 1.2(a)).
- **Electron microscopes** magnify objects to more than 200 000x (spoken: two hundred thousand times) (Figure 1.2(b)).

A camera can be fitted to either type of microscope to take pictures. These pictures are called **micrographs**.

- **Light micrographs** can come out as colour images.
- **Electron micrographs** are black-and-white images, but they can be artificially colourised.

To get a clearer picture of how a cell is constructed, we may need to make a section of the cell at different planes (Figure 1.3).

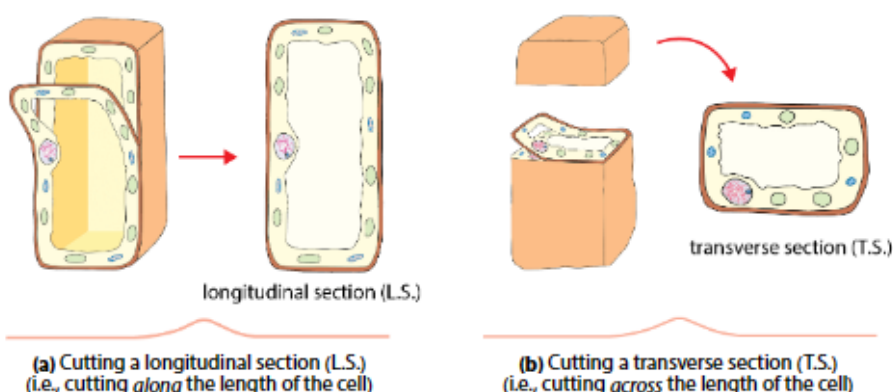


Figure 1.3 We may cut a cell in two different ways in order to view cell structures from different angles. This helps us to build up a three-dimensional picture of the cell.

What Does a Cell Consist Of?

- ▶ A **cell** is a unit of life. It consists of a mass of living matter called **protoplasm**.

While all the cells of your body may not look the same, they all have similar parts. Each living cell consists of living material called **protoplasm** (Greek: *protos* = first; *plasm* = form).

Protoplasm is a complex jelly-like substance. Many chemical activities that allow the cell to survive and grow are carried out in the protoplasm.

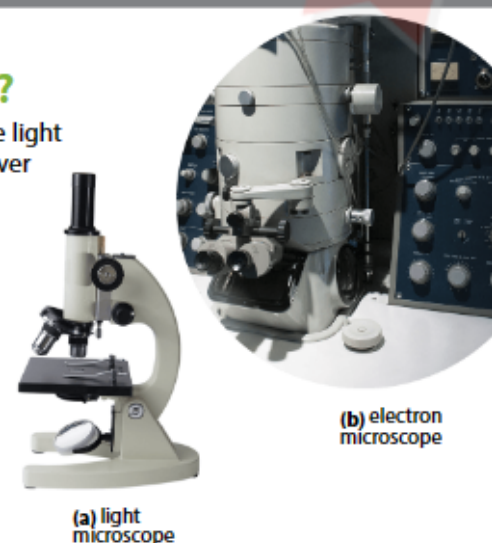


Figure 1.2
Microscopes



Biology Connect

Scan the QR code to watch a clip and have a glimpse of the structures inside the cell.



Disciplinary Idea

Systems

Cells are highly organised biological systems with many organelles. While each organelle performs specific functions, the various organelles work as a co-ordinated system within the cell to carry out processes needed to sustain life.



Word Alert

Mitochondrion: singular for mitochondria

Lipids: biological molecules that are not soluble in water. Examples of lipids are fats, waxes and oils.



Helpful Note

The terms 'cell surface membrane' and 'cell membrane' are used in this book to refer to the membrane enclosing the entire cell. Organelles inside the cell are also enclosed by their own membranes.

The protoplasm of a cell is made up of three parts: the **cell membrane** (also known as **cell surface membrane**), **cytoplasm** and **nucleus** (Figure 1.4).

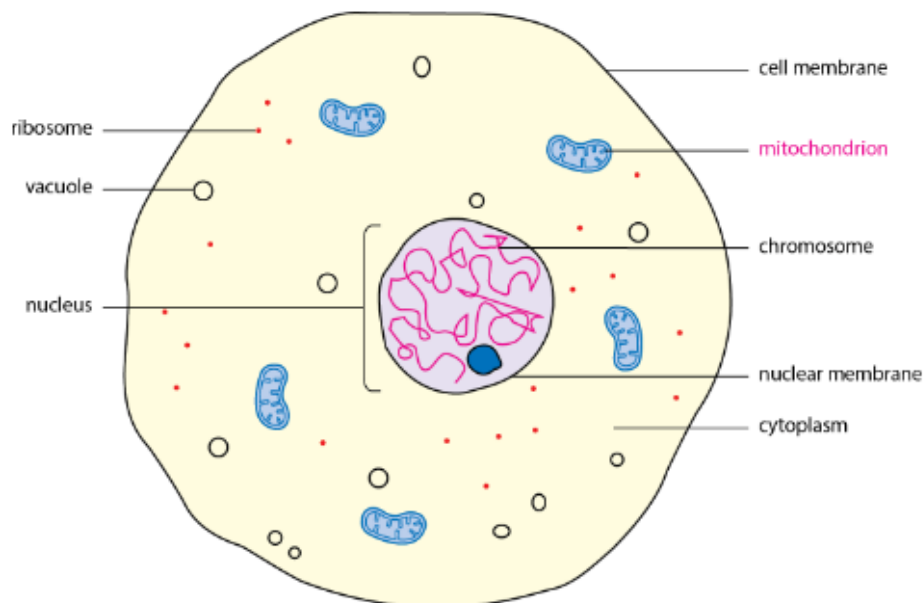


Figure 1.4 A generalised animal cell showing some major organelles

Cell Membrane

The cell membrane surrounds the cytoplasm of the cell. The cell membrane is made up of **lipids** and proteins. It is a **partially permeable membrane**. This means that it allows only some substances to pass through it. Hence, the cell membrane controls the movement of substances in and out of the cell.

Cell Wall

A plant cell also has a **cell wall** that encloses the entire plant cell, surrounding the cell membrane (Figure 1.5). This cell wall is made of **cellulose**. It protects the cell from injury and gives the plant cell a fixed shape. The cell wall is **fully permeable**, so it does not control the type of substances that enter or leave the cell. The cell wall is absent in animal cells.

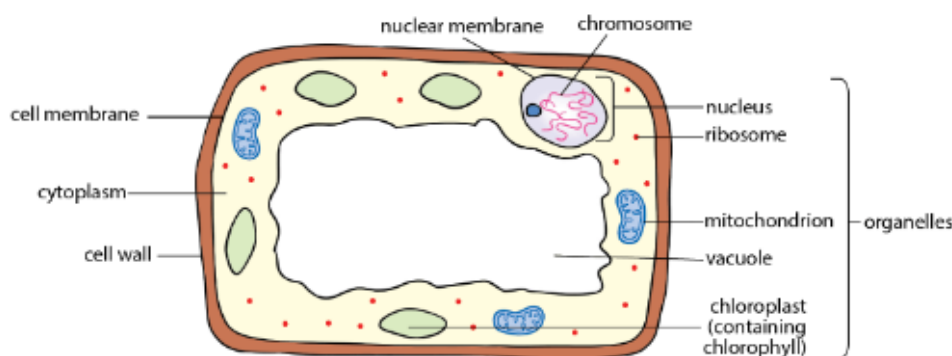


Figure 1.5 A generalised plant cell

Cytoplasm

The cytoplasm is a jelly-like substance that fills the inside of the cell and is enclosed by the cell membrane. It is the part of the protoplasm between the cell membrane and the nucleus. It is where most cell activities occur. The cytoplasm contains organelles. An **organelle** is a cellular structure that performs a specific job within a cell.

Organelles carry out many functions in the cell. You will learn more about them in later parts of this chapter. Many organelles, such as **mitochondria**, **endoplasmic reticulum**, **Golgi body** and **ribosomes** are not visible under the light microscope. They can only be studied under the electron microscope.

What Are the Parts of the Cytoplasm?

The cytoplasm contains tiny structures called organelles (Figure 1.6). Each **organelle** is specialised for a particular function. Examples of these organelles are nucleus, rough endoplasmic reticulum, ribosomes, Golgi body, mitochondria, chloroplasts and vacuoles.

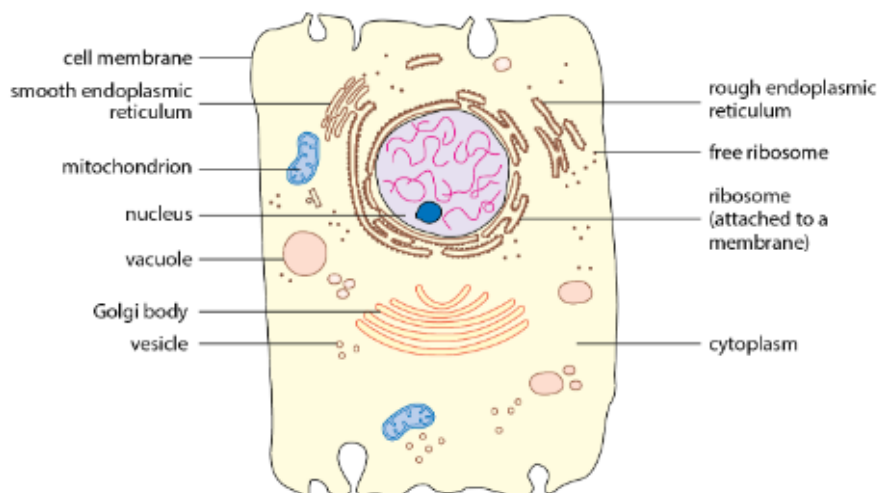


Figure 1.6 Organelles in an animal cell seen under an electron microscope

Nucleus

The nucleus is surrounded by a membrane called the **nuclear membrane**. The nucleus contains genetic information in the form of chromosomes. You will learn more about chromosomes later in this section.

These are the functions of the nucleus:

- It controls cell activities such as cell growth and the repair of worn-out parts.
- It is essential for cell division. Cells without a nucleus, like the red blood cells of a mammal, are unable to divide.

To see the individual parts of the nucleus clearly, we will need to use an electron microscope (Figure 1.7).

Chromosomes

- Each chromosome is a long thread-like structure found within the nucleus. (A human cell contains 46 chromosomes.)
- It is made up of proteins and a compound called deoxyribonucleic acid or DNA. Hereditary information is stored in DNA. DNA carries instructions that a cell needs for carrying out its activities.
- When the cell is dividing, the chromosomes condense and shorten to become thick, rod-shaped structures.

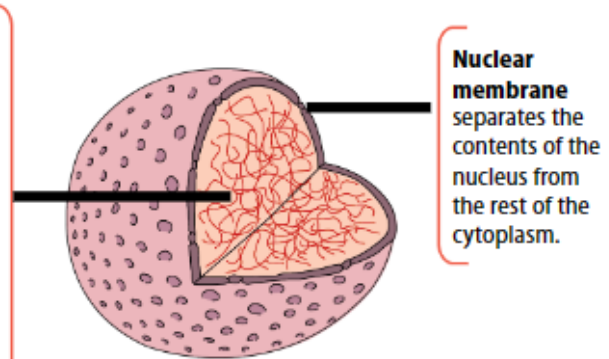
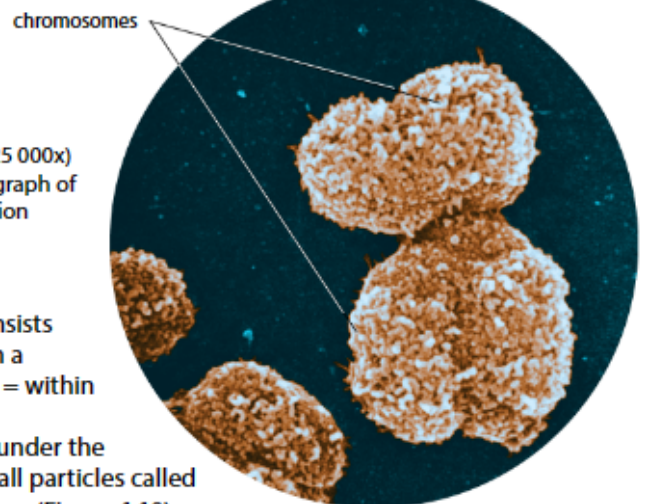


Figure 1.7 Diagram showing parts of the nucleus (three-dimensional reconstruction of images seen under an electron microscope)

Figure 1.8 shows the appearance of chromosomes during cell division.

Figure 1.8 Highly magnified (25 000x) and coloured electron micrograph of chromosomes during cell division



Rough Endoplasmic Reticulum

Rough endoplasmic reticulum (RER) consists of a network of flattened spaces lined with a membrane (Figure 1.9). (Greek: *endoplasm* = within the cytoplasm; *reticulum* = network).

- Its surface appears rough when viewed under the electron microscope. This is because small particles called ribosomes are attached to its outer surface (Figure 1.10).
- The outer surface of the RER is continuous with the nuclear membrane.

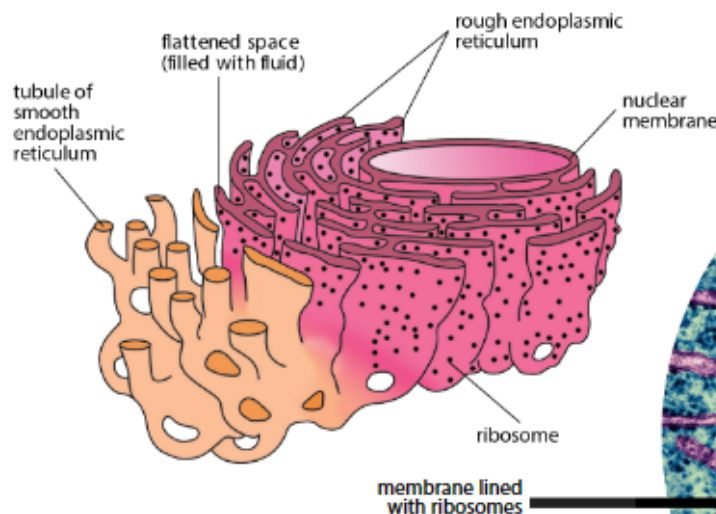
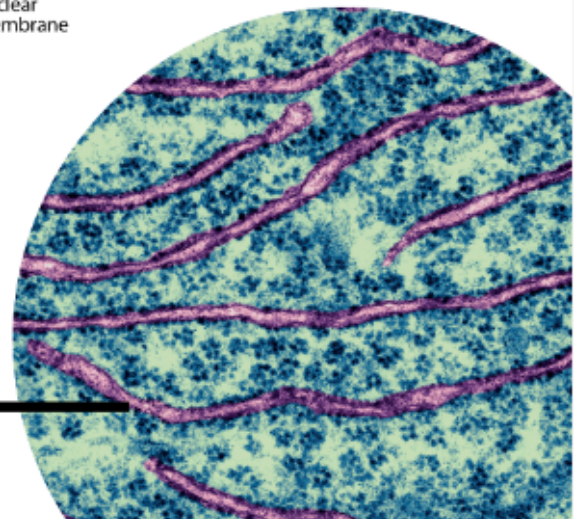


Figure 1.9 Three-dimensional diagram of endoplasmic reticulum

Figure 1.10 Coloured electron micrograph of membrane lined with ribosomes



Ribosomes

Ribosomes are small round structures. They are either attached to the membrane of the rough endoplasmic reticulum (RER) or lie freely in the cytoplasm (Figure 1.6 on page 5). They are needed to synthesise proteins in the cell.

- The ribosomes attached to the RER make proteins that are usually transported out of the cell.
- The ribosomes lying freely in the cytoplasm make proteins that are used within the cytoplasm of that cell.

The RER transports proteins made by ribosomes to the Golgi body for secretion out of the cell.



Link

What role do fats play in your body? Read more about them in Chapter 3. What role do sex hormones play in your body? Read more about them in Chapter 17.

Smooth Endoplasmic Reticulum

Smooth endoplasmic reticulum (SER) does not have ribosomes attached to its membrane. SER is more tubular than RER (see Figure 1.11). It is connected to the RER.

The SER:

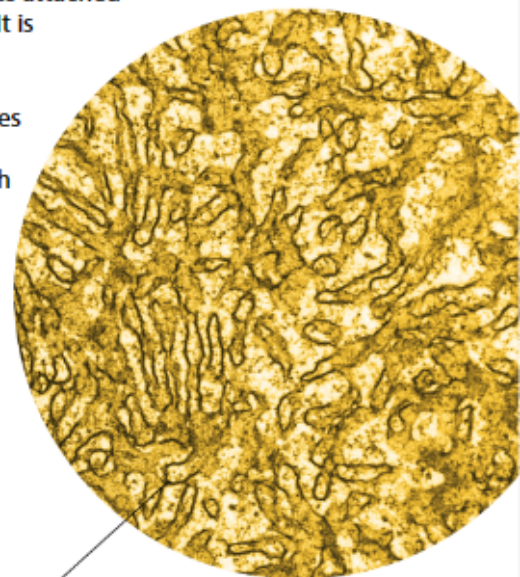
- synthesises substances such as fats and **steroids** (sex hormones in mammals are steroids)
- converts harmful substances into harmless substances through a process known as **detoxification**

Golgi body

The **Golgi body** (also known as **Golgi apparatus**) is shaped like a disc. It consists of a stack of flattened spaces surrounded by membranes. **Vesicles** (tiny spherical spaces enclosed by a membrane) can be seen fusing with one side of the Golgi body and pinching off from the opposite side (Figure 1.12).

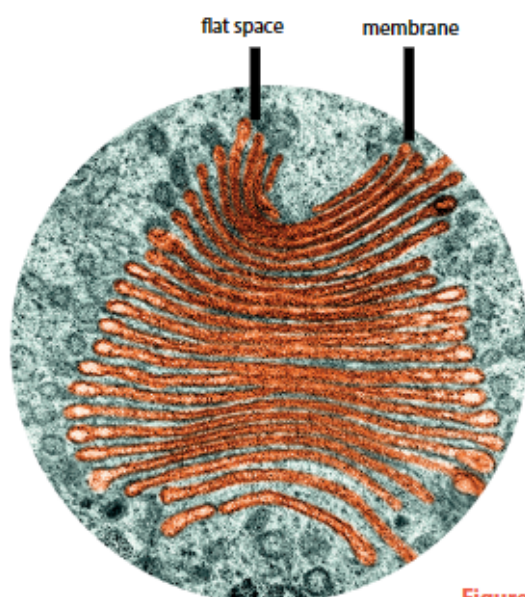
The Golgi body:

- chemically modifies substances made by the ER
- stores and packages these substances in vesicles for secretion out of the cell

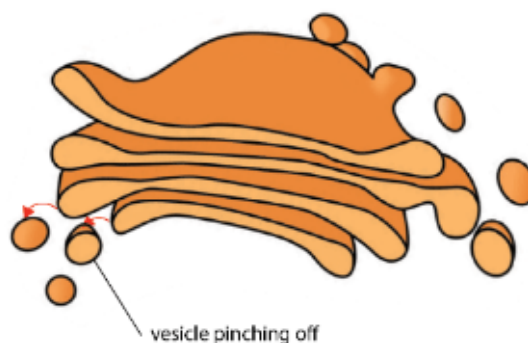


tubule of smooth endoplasmic reticulum

Figure 1.11
Colourised electron micrograph of SER



(a) Colourised electron micrograph of Golgi body (6 250 $\times$)



(b) Three-dimensional view of Golgi body

Figure 1.12 Golgi body

Figure 1.13 shows how substances made by the ER are moved out of the cell.

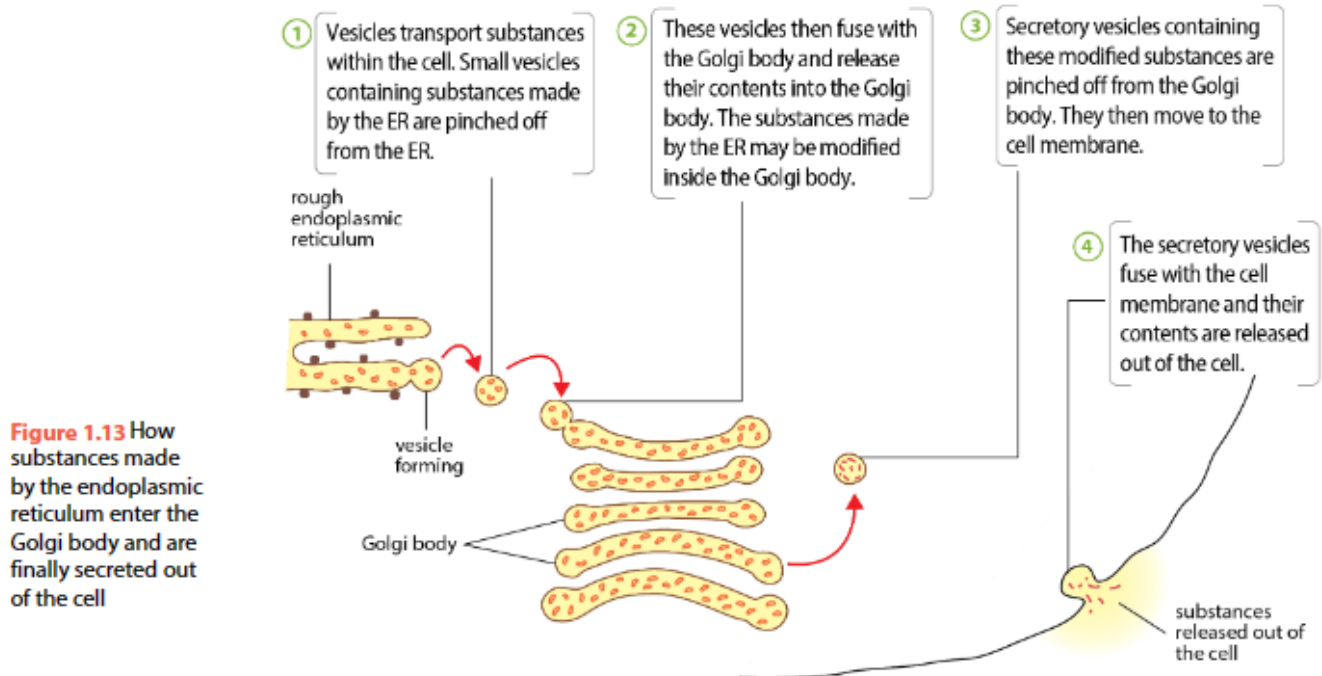


Figure 1.13 How substances made by the endoplasmic reticulum enter the Golgi body and are finally secreted out of the cell

Other organelles embedded in the cytoplasm are the mitochondria, chloroplasts (only in plant cells) and vacuoles.

Mitochondria

Mitochondria (singular: mitochondrion) are small oval or sausage-shaped organelles (Figure 1.14). Aerobic respiration occurs in the mitochondria. During aerobic respiration, food substances are broken down to release energy (see Chapter 7). This energy may be used by the cell to perform cell activities such as growth and reproduction.

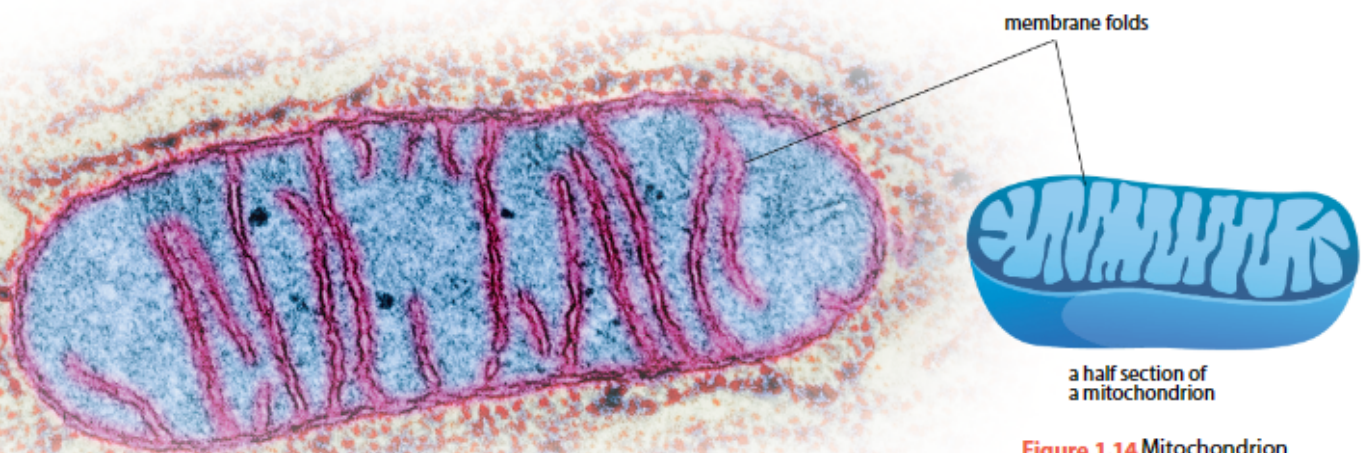


Figure 1.14 Mitochondrion



Compare the general structure of the plant cell (Figure 1.15(a)) with that of the animal cell (Figure 1.15(b)). Do you notice any difference(s) between the two cells?

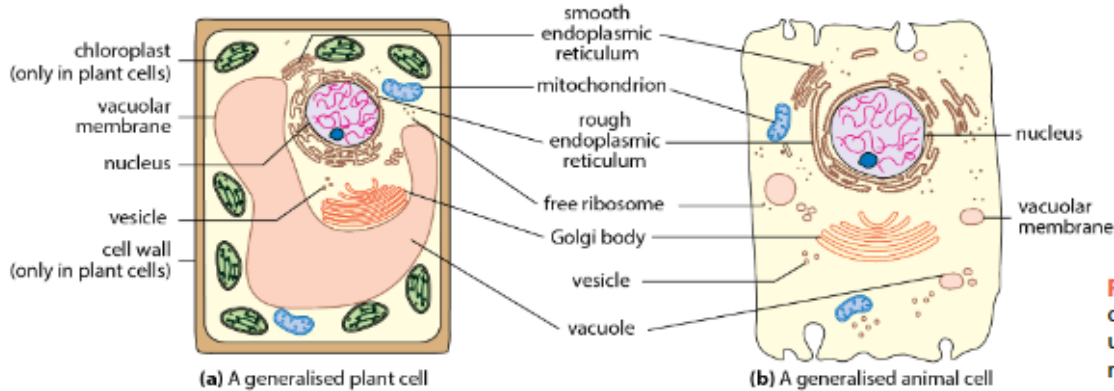
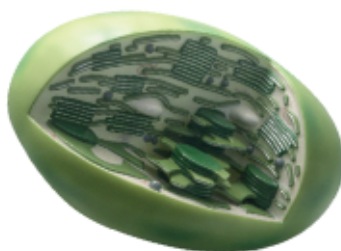


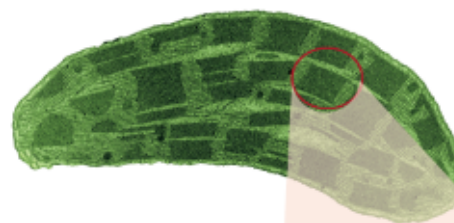
Figure 1.15 Diagrams of cells as seen under an electron microscope

Chloroplasts

- **Chloroplasts** are oval structures found in plant cells (Figure 1.16).
- Chloroplasts contain a green pigment called **chlorophyll**.
- Chlorophyll is essential for photosynthesis, the process by which plants make food (see Chapter 12).



(a) Three-dimensional diagram of a chloroplast



(b) Colourised electron micrograph of a section of a chloroplast

Figure 1.16 Chloroplast

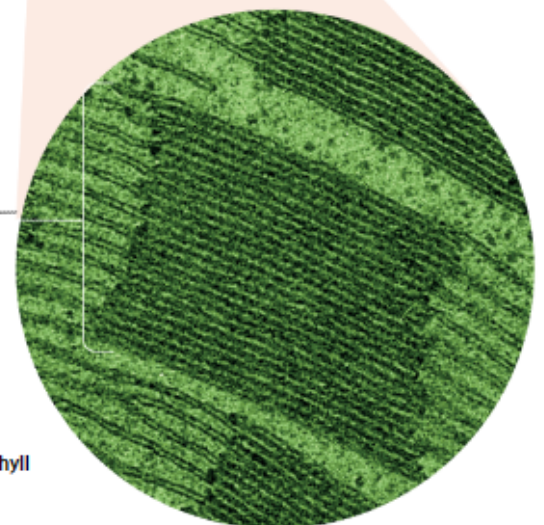
Vacuoles

A **vacuole** is a fluid-filled space enclosed by a partially permeable membrane. Vacuoles store substances within the cell.

Plant cells have a large central vacuole which contains a liquid called cell sap. *Cell sap* contains dissolved substances such as sugars, mineral salts and amino acids.

Animal cells have many small vacuoles that contain water and food substances. These vacuoles usually exist temporarily.

stack of membranes containing chlorophyll





Helpful Note

Methylene blue is a dye that stains structures in a sample, making parts of the cell more visible.

Let's Investigate 1.1

Aim

To examine animal cells using a light microscope

Procedure

- 1 Place a drop of methylene blue on a clean microscope slide.
- 2 Gently scrape the inside of your cheek with a blunt end of a clean toothpick. Swirl the toothpick end in the drop of methylene blue.
- 3 Carefully lower a cover slip at an angle over the slide.
- 4 Examine the cells on the slide under a light microscope.
- 5 Draw one cheek cell and label it as fully as you can.

Observation

Figure 1.17 shows human cheek cells viewed under the light microscope.

Discussion

- 1 Compare your drawing with the diagram of an animal cell in Figure 1.4 on page 4. Which structures shown in Figure 1.4 are not visible under the light microscope?
- 2 Why must the cover slip be lowered at an angle in step 3?

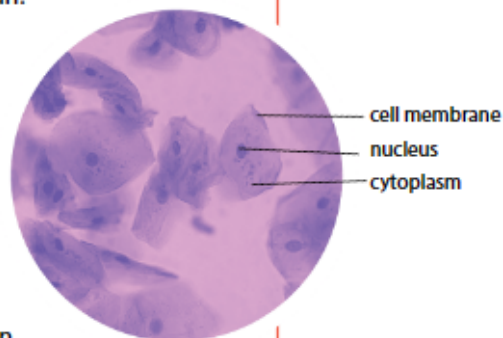


Figure 1.17

Let's Investigate 1.2

Aim

To examine plant cells using a light microscope

Procedure

- 1 Take a fleshy scale leaf from an onion bulb and bend the leaf until it breaks into two. Gently peel off the skin, called the epidermis, from the inner surface of the leaf using a pair of forceps.
- 2 Place the epidermis on a clean glass slide.
- 3 Add a drop of iodine solution (or methylene blue) in the middle of the slide. Carefully lower a coverslip at an angle over the slide.
- 4 Examine the epidermis under the microscope.
- 5 Draw one epidermal cell and label it as fully as you can.

Observation

Figure 1.18 shows onion epidermal cells viewed under the light microscope.

Discussion

- 1 How does this cell differ from the plant cell in Figure 1.5 on page 4?
- 2 State **two** differences between plant and animal cells that are visible under the light microscope.

Hint Look at shape and cell structures.

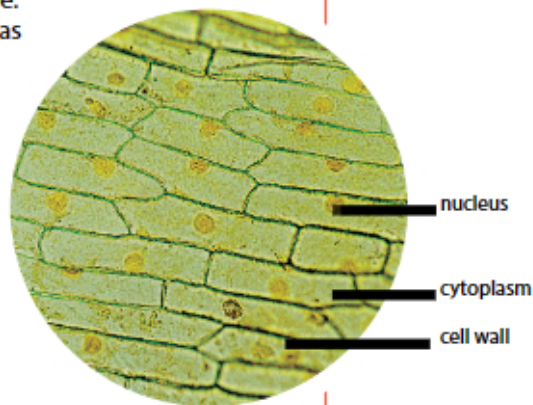


Figure 1.18



Link

Practical Workbook
Experiments 1A–1B



Disciplinary Idea

The Cell

Cells are the basic units of life. The different organelles of a typical plant and animal cell carry out specific cellular process. The differences in organelles found in plant and animal cells can explain the differences in functions between plants and animals.

Differences Between Plant and Animal Cells

Table 1.1 shows the key differences between plant and animal cells.

Table 1.1 Differences between plant cells and animal cells

Plant Cell	Animal Cell
Cell wall present	Cell wall absent
Presence of a large, central vacuole	Presence of many small vacuoles
Chloroplasts present	Chloroplasts absent



Helpful Note

A tissue is a group of cells with similar structures which work together to perform a specific function. There are two types of tissues: simple tissue and complex tissue. An example of simple tissue is the muscular tissue. Complex tissues contain more than one type of cells, e.g. blood (Figure 1.19) and xylem (Figure 1.20).

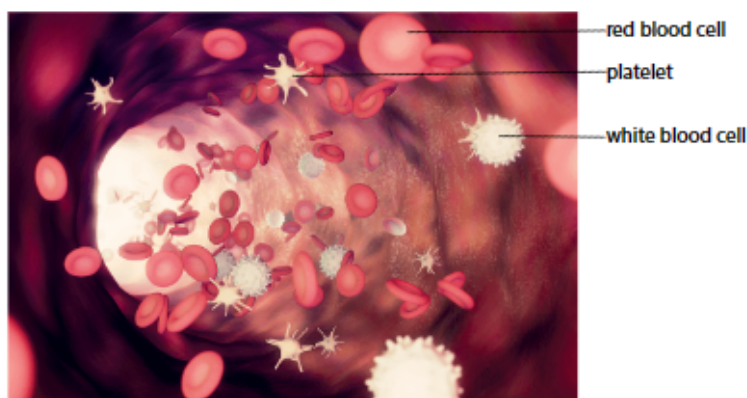


Figure 1.19 Blood contains red blood cells, white blood cells, platelets and plasma.

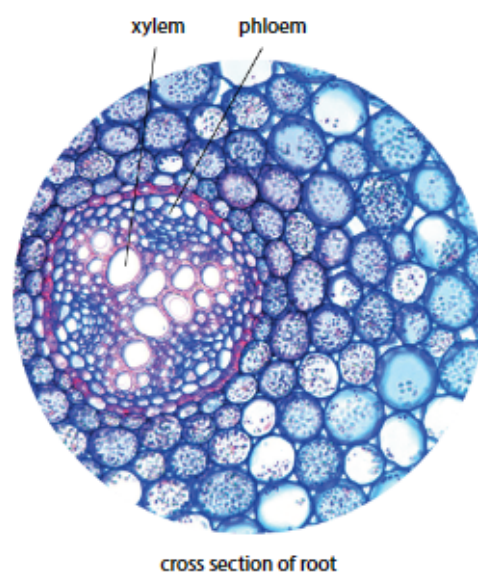


Figure 1.20 Plants contain xylem and phloem tissues that work together for a specific function.

An organ consists of more than one kind of tissue, all working together to perform a specific function. Examples of organs are the stomach and leaf.

An organ system consists of several organs working together for a common purpose. Examples of organ systems in humans include the digestive system, circulatory system, respiratory system and transport system. In plants, examples of organ systems include the root system and the shoot system. Various systems together make up the entire body of an organism.

Let's Practise 1.1

- 1 State the functions of the following membrane systems and organelles in the cell:

(a) chloroplasts	(e) rough endoplasmic reticulum
(b) Golgi body	(f) smooth endoplasmic reticulum
(c) mitochondria	(g) vacuoles
(d) ribosomes	
- 2 State **three** differences between a plant cell and an animal cell.
- 3 Figure 1.21 shows a picture of a typical cell.
 - (a) Identify the parts A, B and C.
 - (b) Is this an animal cell or a plant cell? Give **three** reasons for your answer.

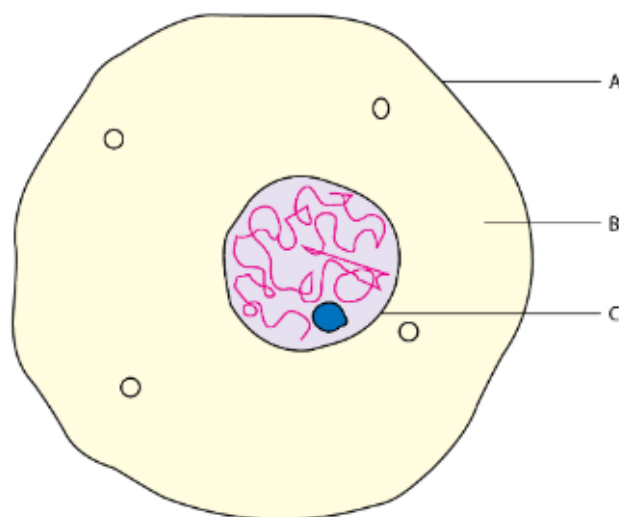


Figure 1.21



Link

Theory Workbook
Worksheet 1A

1.2 How Are Cells Adapted to Their Functions?

Learning Outcome

- Explain how the structures of specialised cells are adapted to their functions (e.g. muscle cell – many mitochondria to supply more energy, root hair cell – large surface area of cell membrane for greater absorption, red blood cell – lack of nucleus allowing it to transport more oxygen).

There are many different types of cells in living organisms. These cells differ in size and shape and they perform specific functions. For example:

- the human body has liver cells, nerve cells and skin cells, and
- the bougainvillea plant has guard cells and root hair cells.



Link

A nerve cell looks very different from the generalised cell you have learnt. Read more about it in Chapter 10.

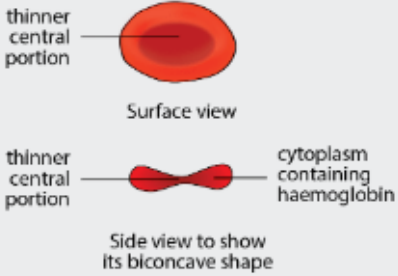
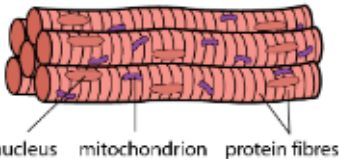
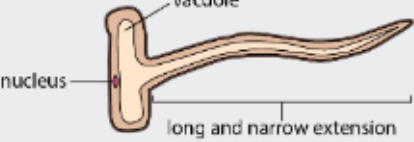
Some cells develop special structures or lose certain structures to enable them to carry out specific functions. This process of development is called **differentiation**.

► **Differentiation** is the process by which a cell becomes specialised for a specific function.

How Is the Structure of a Cell Related to Its Function?

Table 1.2 shows some specialised cells and how they have been modified for specific functions.

Table 1.2 Examples of specialised cells and their adaptations

Cell Structure	Adaptation to Function
Red blood cell  thinner central portion Surface view thinner central portion Side view to show its biconcave shape cytoplasm containing haemoglobin	- Contains haemoglobin (a red pigment) which binds to oxygen and transports it around the body - Has a circular, biconcave shape which increases the surface area-to-volume ratio so that oxygen can diffuse in and out at a higher rate - Lacks a nucleus, enabling the cell to store more haemoglobin for transport of oxygen - Is flexible and can squeeze through capillaries easily
Muscle cell  nucleus mitochondrion protein fibres	- Is elongated and cylindrical in shape, contains many nuclei and mitochondria - Has mitochondria to provide the energy for the contraction of the muscle cell
Root hair cell  vacuole nucleus long and narrow extension	Has a long and narrow root hair to increase the surface area-to-volume ratio to absorb water and mineral salts at a higher rate



Disciplinary Idea Structure and Function

Specialised cells have structures which help them carry out their functions more efficiently.



Link

How does surface area-to-volume ratio affect the movement of substances into and out of cells? Read more about it in Chapter 2.



Word Alert

biconcave: curving in on both sides, hence being thinner in the middle than the edges



Cool Career

Plant Tissue Culture Scientist

Plant cells have an amazing ability to develop into an entire plant. This ability is called cellular totipotency. Plant tissue culture scientists make use of this ability to develop plants in the laboratories from plant tissue culture (Figure 1.22). This method reduces the time to produce new varieties, as compared to traditional breeding methods.

Plant tissue culture has far-reaching applications, especially in agriculture. Specific breeds of plants that are resistant to diseases can now be produced in large numbers. In forestry, this technique is useful for large scale **propagation** of forest trees.

How do you think this technique can help our environment and improve the lives of people in less developed countries?



Word Alert

Propagation: growing and planting new trees

Figure 1.22 Scientist cutting plant tissue culture in a Petri dish

Let's explore some ideas about cells (Figure 1.23). Are all cells in an organism the same? Which student is correct?

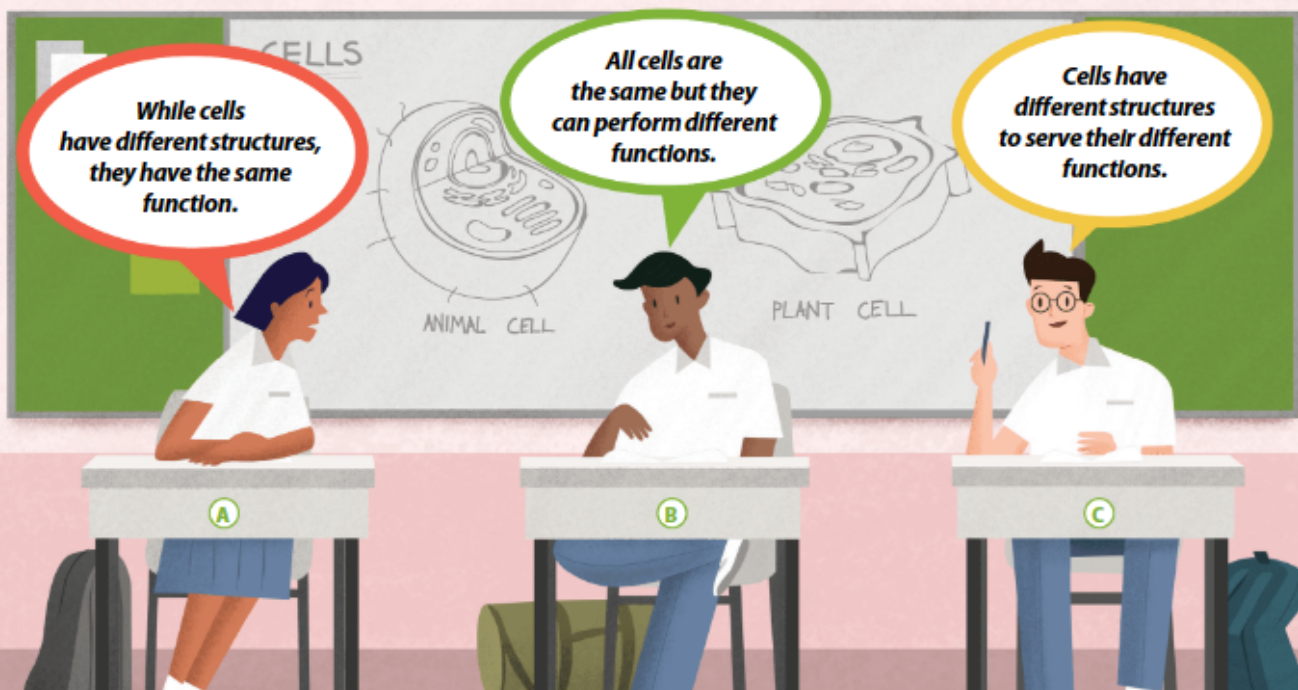


Figure 1.23 Three students are giving their views on cells. Which student is correct?



Tech Connect

We can now create chicken meat from chicken muscle cells cultured in the laboratory (Figure 1.24). Would this mean that we can produce a functioning organ in the laboratory by using cells that form the particular organ?

Scientists may be able to make a three-dimensional model of an organ in the laboratory. However, many natural biological reactions taking place in an organ system cannot be reproduced in a model. Tissue engineers can now study a variety of natural biological reactions in an organ by placing the respective cells on a microchip. A simplified model for study is created in this way.

These do not look anywhere near how our natural organs may look, but they are functional and they enable scientists to study the processes that take place in each organ, with almost complete control within the laboratory.

Find out more about the benefits of using models to study processes in the human body.



Figure 1.24 Meat cultured in the laboratory from stem cells



Past to Present

For many years, scientists and doctors have been injecting healthy blood stem cells into patients who suffer from leukaemia, a type of cancer of the blood. This method, known as bone marrow transplant, has been a highly effective treatment, increasing the survival rates of patients substantially.

In recent years, scientists have developed several other methods of using cells to treat different diseases. These methods use a special type of cell called stem cells. Stem cells, unlike other cells in the body, are not specialised cells and thus have the ability to develop into other specialised cell types (Figure 1.25). This opens up a whole range of possibilities. Cells of different organs can be potentially grown in the laboratory and transplanted into the organs of humans. A patient's immune cells could be modified to recognise cancerous cells in the lymph nodes and destroy them.

There are still a lot of challenges that scientists need to overcome. In the near future, we may be able to make use of cells to treat diseases that were once considered untreatable.

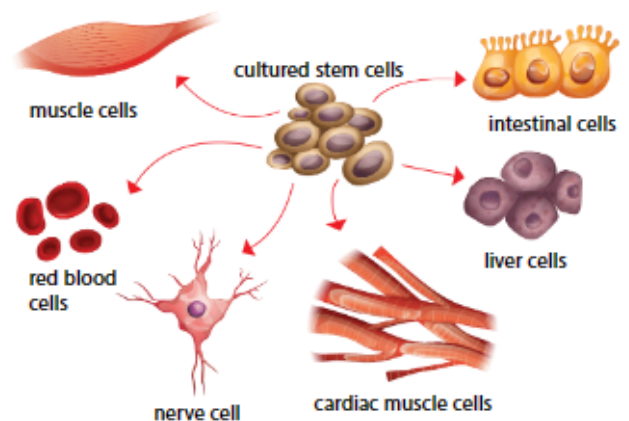
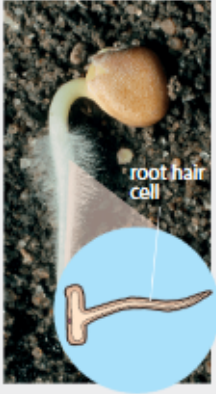
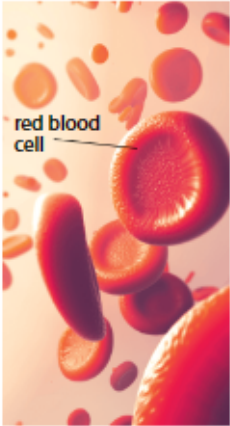


Figure 1.25 Human stem cells can be used to develop a variety of cells.

Let's Practise 1.2

Look at the structure and cells in Table 1.3. Complete the table to describe how these cells have been adapted to carry out its functions.

Table 1.3

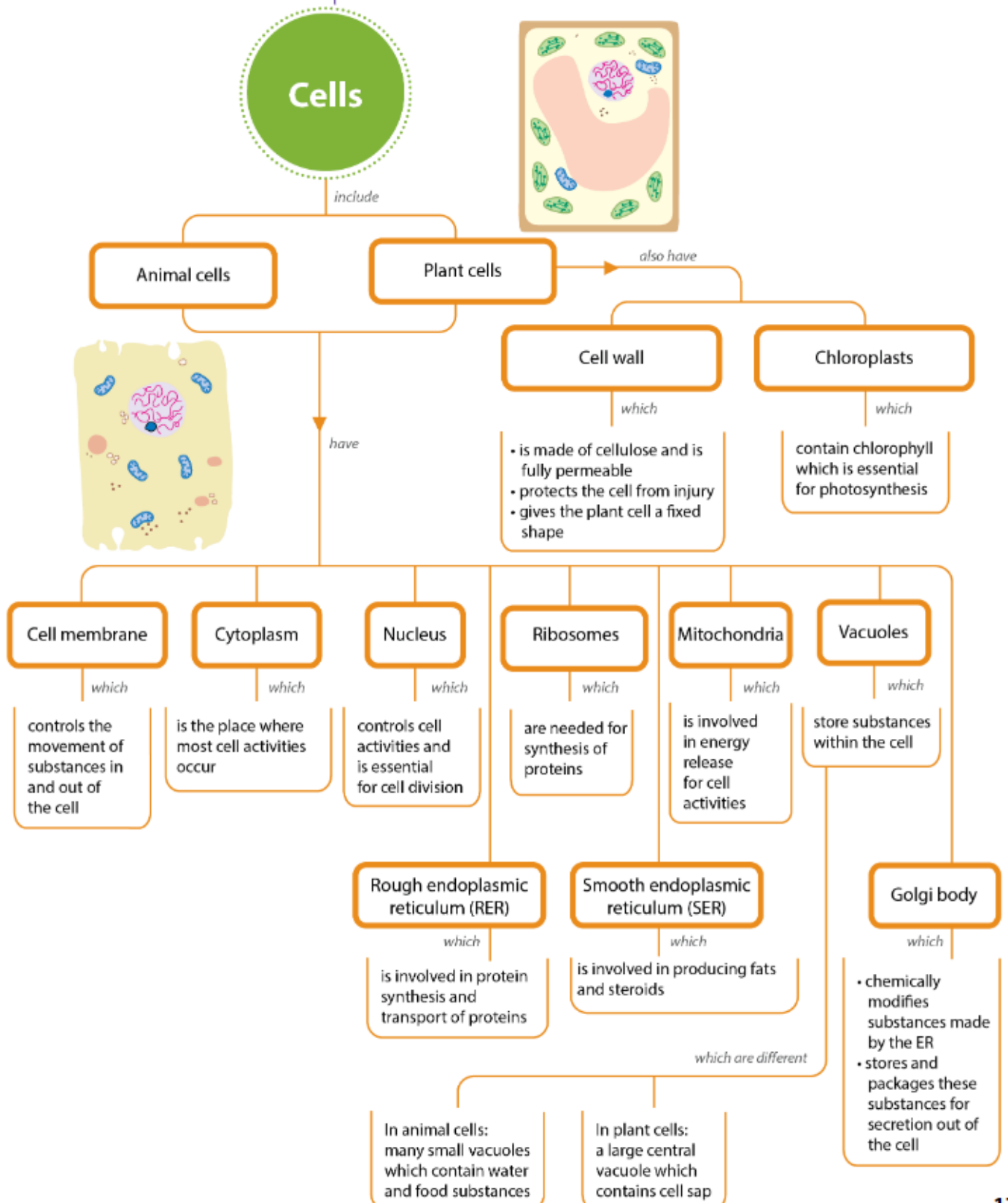
Cell	Function	Important Characteristic(s) to Serve Its Function Well	How These Characteristics Help It to Perform Its Functions
 root hair cell	To absorb water and mineral salts from the soil		
 red blood cell	To deliver oxygen to all parts of the body		



Link

Theory Workbook
Worksheet 1B
Let's Assess
Let's Reflect

Let's Map It



Let's Review

Section A: Multiple-choice Questions

1 Which of the cell organelles is **not** visible under the ordinary light microscope?



- ☐ A cellulose cell wall
- ☐ B cellulose cell wall and nucleus
- ☐ C chloroplasts
- ☐ D Golgi body and rough endoplasmic reticulum

2 Figure 1.26 shows a typical plant cell. Which of the numbered structures are partially permeable?

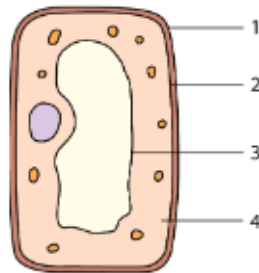


Figure 1.26



- ☐ A 1 and 2
- ☐ B 1 and 4
- ☐ C 2 and 3
- ☐ D 3 and 4

Section B: Structured Questions

1 Name the structure in the cell that:

- (a) controls the movement of substances in and out of the cell;
- (b) contains genetic information;
- (c) is involved in cell respiration;
- (d) stores and modifies substances made by the ER for secretion out of the cell.

2 Look at the list of cell structures:

cell membrane, large central vacuole, cytoplasm, nucleus, chloroplasts, mitochondria, endoplasmic reticulum, Golgi body, ribosomes

Which of the structures listed above are:

- (a) present in both plant and animal cells?
- (b) present in plant cells only?

3 Figure 1.27 shows three different cells seen under the microscope. Which is a plant cell? Explain your answer.

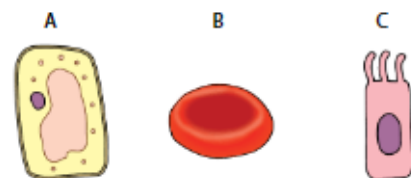


Figure 1.27

Section C: Free-response Question

1 Describe how proteins synthesised by ribosomes are transported out of the cell.

CHAPTER

02 Movement of Substances



What You Will Learn



- What is diffusion?
- What is osmosis?
- What is active transport?

Think like a chef and act quickly! Two chefs are cooking potatoes. Each potato needs to be cut into four pieces. Each potato also needs to be soaked in water before cooking.



Chefs Nurul and Faridah took a potato each and scraped off its skin.

Chef Nurul cut the potato into four pieces before soaking it in water for one hour. Chef Faridah soaked the potato in water for one hour before cutting it into four pieces.

Which chef will need to exert more strength to cut the potatoes? Why do you think so? What role does the potato skin play?

2.1 What Is Diffusion?

Learning Outcomes

- Define diffusion and describe its role in nutrient uptake and gaseous exchange in plants and humans.
- Describe the factors that affect the rate of diffusion.

Diffusion

Imagine that you are sitting in the living room reading a book. Your sister accidentally spills a bottle of perfume in the living room. Gradually, you become aware of a pleasant scent spreading through the living room.

Figure 2.1 illustrates how diffusion takes place.



Figure 2.1 Diffusion of perfume particles

- ① Perfume, like all matter, is made up of particles such as atoms, molecules or ions.
- ② Individual particles of perfume evaporate from the surface of the spill, that is, they become a gas.
- ③ The gas particles have kinetic energy and are constantly moving in all directions. They bump into one another and move about randomly.
- ④ This causes the gas to spread throughout the house, until it reaches your nose and you smell it. The gas spreads outwards through a process called *diffusion*.

What Is a Concentration Gradient and How Is It Related to Diffusion?

In Figure 2.1, point A represents the location where the bottle of perfume was spilled. Point B represents you in the living room, some distance away. Concentration refers to the amount of a substance within a fixed volume. The concentration of gas particles is higher at A than at B. Thus, there is a difference in concentration between points A and B. This concentration difference can be shown on a graph (Figure 2.2) and is referred to as the concentration gradient.



Link

Physics

We learn that the random movement of microscopic particles is known as Brownian motion.

In Figure 2.2, the height of the blue line shows the concentration at each point. If we join the concentrations at A and B, we get a straight line, which is sloped or has a gradient. This red dotted line is the *concentration gradient* between A and B.

- **Concentration gradient** is the difference in concentration between two regions.

The particles of fluids (liquids and gases) possess movement (kinetic) energy. They are continuously moving about. As their movement is random, the particles will move (diffuse) down the concentration gradient and become evenly spaced out after some time (Figure 2.3).

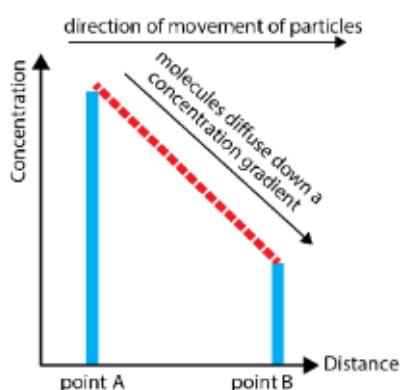


Figure 2.2 Graphical representation of diffusion

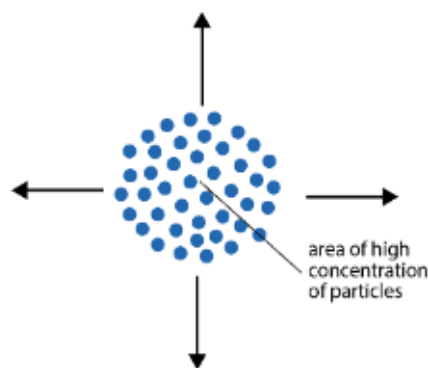


Figure 2.3 Arrows showing direction of movement of particles as they space out

In Figure 2.1, the smell of perfume diffuses throughout the house.

- *Diffusion* can thus be described as the net movement of particles down a concentration gradient.
- *The steeper the concentration gradient for a substance, the faster the rate of diffusion for that substance.*

- **Diffusion** is the net movement of particles (atoms, molecules or ions) from a region where they are of higher concentration to a region where they are of lower concentration, that is, down a concentration gradient.

Let's Investigate 2.1

Aim

To investigate the diffusion of a dissolved substance in water

Procedure

- 1 Drop a copper(II) sulfate crystal into a gas jar full of water as shown in Figure 2.4. Cover the jar and allow it to stand for a few days.
- 2 Observe the changes in the colour of the water.

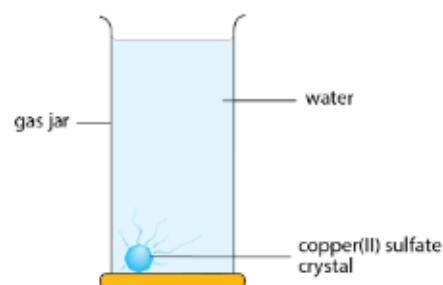


Figure 2.4 Experimental set-up to demonstrate diffusion



Link

Chemistry

We learn that all matter is made up of tiny particles that are in constant random motion. These moving particles have kinetic energy.



Helpful Note

Net movement refers to the overall movement of particles. Net movement of particles occurs when the movement of particles in one direction is greater than the movement of particles in the opposite direction.

When the two regions have the same number of particles per unit volume, the movement of the particles between the two regions will be the same in both directions. Thus, there will be no net movement.

Observation and Discussion

- 1 Using the concept of concentration gradient, explain why the blue colour of copper(II) sulfate gradually spreads throughout the water in the jar.
- 2 When does diffusion stop?

As you saw in Let's Investigate 2.1, the particles of copper(II) sulfate moved from a region of higher concentration to regions of lower concentration in the surrounding water. In other words, the solute particles diffused evenly throughout the liquid to form a solution.

If there is more than one substance dissolved in the same liquid, then the dissolved particles of one substance will diffuse independently of the others.

Diffusion Across a Membrane

Figure 2.5 illustrates the process of diffusion through a permeable membrane. A permeable membrane allows both the solvent (water) and the solutes (the dissolved substances) to pass through it.

As a result:

- The dissolved particles of copper(II) sulfate will diffuse across the membrane to the left side of the beaker.
- The dissolved particles of potassium nitrate will diffuse across the membrane to the right side of the beaker.

Eventually, there will be equal concentrations of all particles on both sides of the membrane.

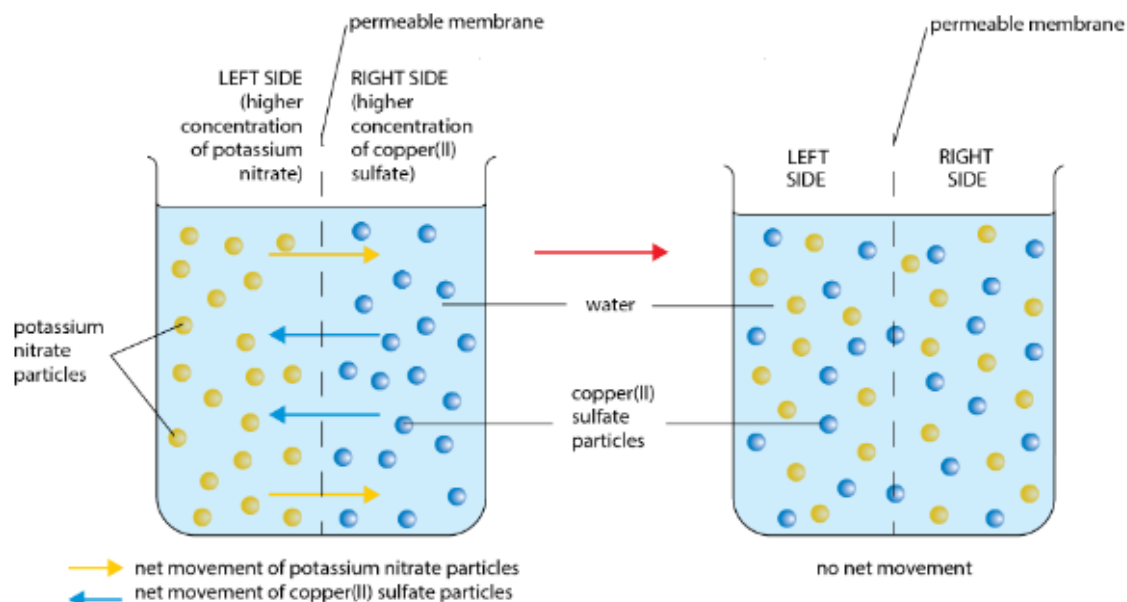


Figure 2.5 Diffusion of potassium nitrate and copper(II) sulfate particles through a permeable membrane

Factors That Affect the Rate of Diffusion

The rate of diffusion can be affected by factors such as:

- concentration gradient
- diffusion distance
- surface area-to-volume ratio

How concentration gradient affects the rate of diffusion has been discussed on page 21.

Diffusion Distance

The time taken for a substance to move from one point to another depends on the distance between the two points. The distance through which a substance diffuses is called the diffusion distance. The shorter the diffusion distance, the less time is needed for the substance to travel, and hence the rate of diffusion is higher.

In living organisms, the cell membrane is not like the membrane in Figure 2.6. It allows some substances to pass through but not others. For example, oxygen and carbon dioxide can pass through the cell membrane but proteins cannot. *Diffusion is an important way by which oxygen and carbon dioxide move into and out of cells.*

Exchange of oxygen and carbon dioxide in the lungs takes place by diffusion (Figure 2.6(a)). Plant cells such as root hair cells also take in oxygen and remove carbon dioxide by diffusion (Figure 2.6(b)). In both these scenarios, the diffusion distance is short, allowing diffusion to occur at a higher rate.



Link

How do humans carry out gas exchange? Read about it in Chapter 7.

How do plants carry out gas exchange? Read about it in Chapter 12.



Disciplinary Idea

Systems

Living organisms rely on diffusion to facilitate the exchange of gases with the environment needed for survival.

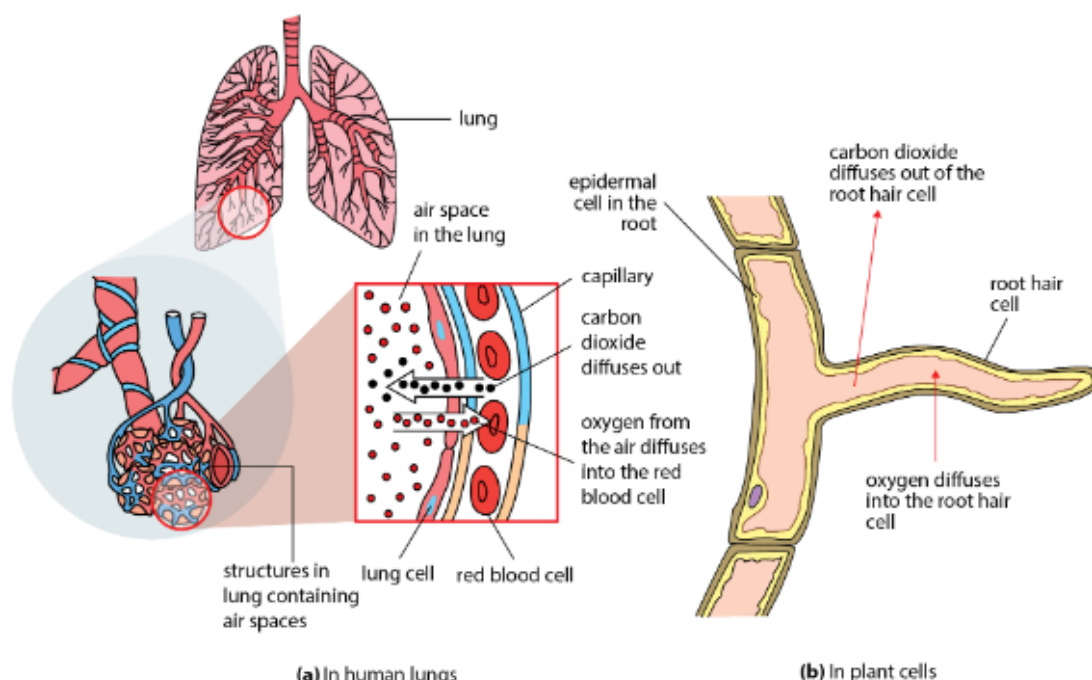


Figure 2.6 Gas exchange of oxygen and carbon dioxide via diffusion

Solutes can also diffuse, for example, in the small intestine when dissolved amino acids and glucose are absorbed by diffusion into the blood capillaries. A solute is a substance that has been dissolved in another substance.

Surface Area-to-volume Ratio

What does surface area-to-volume ratio mean to a cell?

Why are cells typically small? Why do all large organisms always have bodies made up of many small cells and not just one large cell?

The answers to these questions are related to the rate at which materials move across the cell membrane. Cells need to move oxygen, nutrients and waste materials across their cell membrane fast enough to stay alive.

The rate of movement of a substance across a cell membrane depends on how large the cell membrane is (i.e. the surface area of the cell). For two cells of the same volume, the one with the larger surface area allows for a higher rate of diffusion. The ratio between the surface area and volume of a cell is called surface area-to-volume ratio, and is an essential concept in biology. The greater the surface area-to-volume ratio of a cell, the higher the rate at which substances move in and out of it.

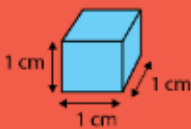
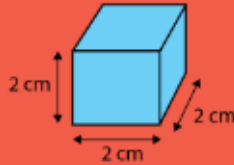
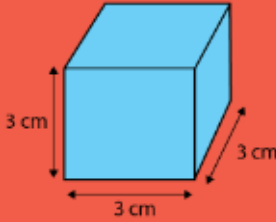
The following investigation will help you better understand surface area-to-volume ratios.

Let's Investigate 2.2

Calculating Surface Area-to-volume Ratios

- 1 Consider three cubes of sides 1 cm, 2 cm, and 3 cm respectively. We use three cubes to represent cells of different sizes.
- 2 Complete Table 2.1.

Table 2.1 Surface area-to-volume ratio of three cubes representing cells of different sizes

Cube			
	sides 1 cm	sides 2 cm	sides 3 cm
Surface area	Area of one face = 1 cm × 1 cm = 1 cm ² Surface area = number of faces × area of one face = 6 × 1 cm ² = 6 cm ²		
Volume	Volume = 1 cm × 1 cm × 1 cm = 1 cm ³		
Surface area-to-volume ratio	6 cm ² : 1 cm ³		



Helpful Note

A cube has six square faces. To find the surface area of a cube, find the area of one face and multiply by six.

From our calculations, we can observe that as the cube becomes bigger, the surface area does not increase in the same proportion as the volume. The cube of sides 1 cm has 6 cm² of surface area to 1 cm³ volume. But the cube of sides 3 cm has only 2 cm² of surface area to 1 cm³ volume. The largest cube has the smallest surface area-to-volume ratio. The rate of movement of substances across the largest cube is the slowest. Thus, as a cell grows, the rate of movement of substances across a cell will decrease.

Let's explore the efficiency of diffusion in three types of cells using the models in Figure 2.7.

In Figure 2.7, the larger cell B has more surface area than cell A, but it has less surface area for every unit volume of protoplasm compared to A. The rate of intake of food and oxygen per unit volume is therefore slower in cell B than in cell A.

The cells in root tips and shoot tips are small and actively growing. As a cell continues to grow in size, its growth slows down and stops once it reaches its optimum size. This is because as the cell grows larger, the rate of oxygen and food intake slows down. Thus, it will not be beneficial for a cell to grow too big.



Word Alert

Optimum: best or most favourable

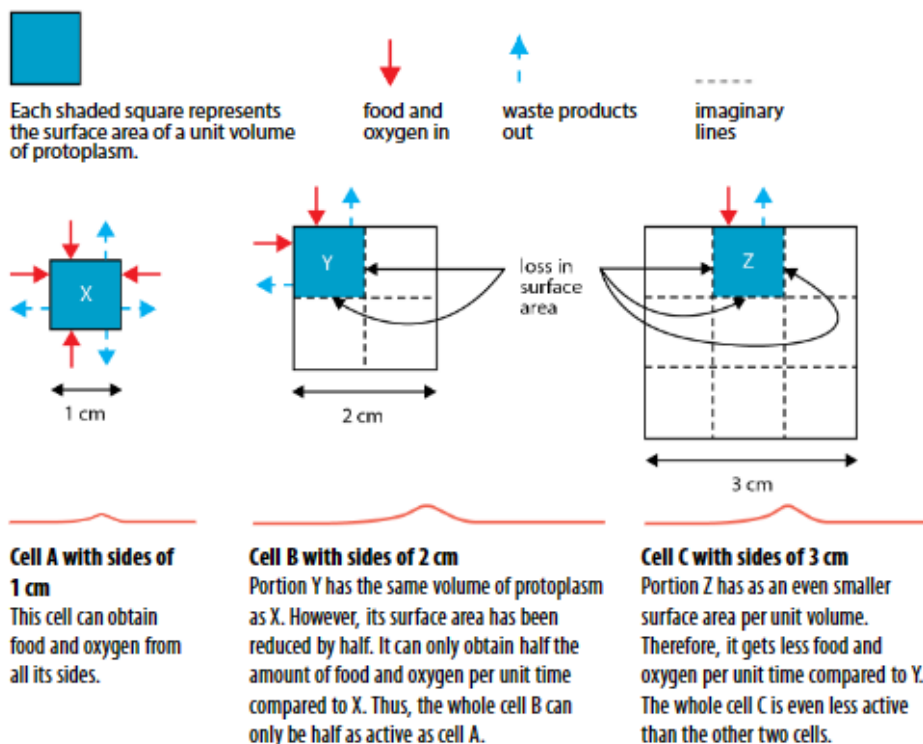


Figure 2.7 Models to explain what surface area-to-volume ratio means to a cell of increasing size

How do cells adapt their surface area-to-volume ratios?

Consider the two shapes in Figure 2.8. Each represents a cell. Cells A and B have the same volume of 1 cm^3 but have different surface areas. What is the surface area-to-volume ratio for cells A and B?

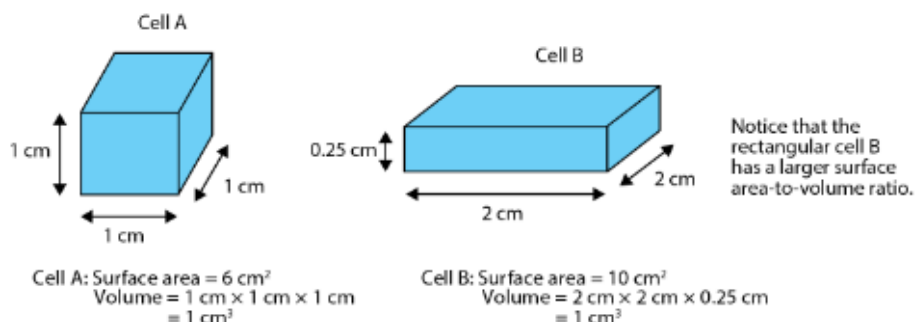


Figure 2.8 Models to explain how cells of the same volume can have different surface areas



Link

How is the root hair cell adapted to its function? Recall what you have learnt in Chapter 1.



Word Alert

Protrusions: things that stick out from the surrounding surface
Lumen: hollow space of a tubular structure

Some cells are specifically adapted to absorb substances, for example, root hair cells and the epithelial cells, which line the small intestine (Figure 2.9). Such cells often have long narrow protrusions or folds in their membranes. These greatly increase the surface area-to-volume ratio of the cell membrane through which materials can be absorbed into the cell. You will learn more about this in Chapter 5.

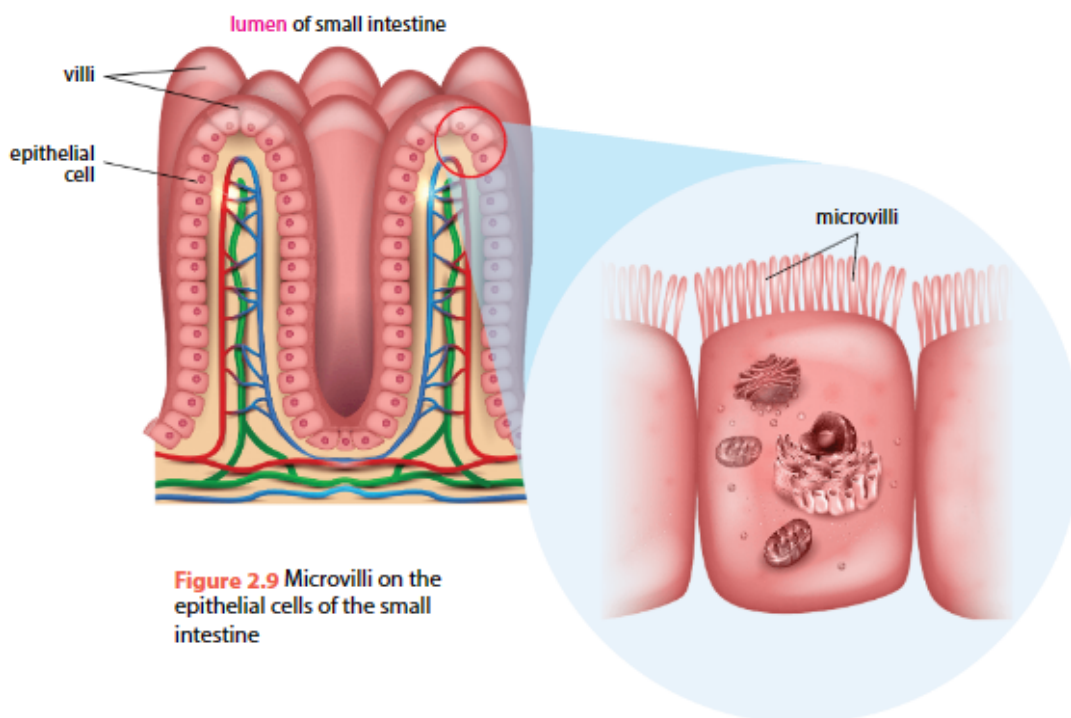


Figure 2.9 Microvilli on the epithelial cells of the small intestine

Let's Investigate 2.3

Aim

To investigate the relationship between surface area-to-volume ratio and absorption

Procedure

- 1 Use a knife and cut out three blocks of agar (stained with bromothymol blue) with the dimensions (in cm) shown in Figure 2.10.
- 2 Completely immerse the three agar blocks in dilute hydrochloric acid and note the time.
- 3 As the acid diffuses into the blocks, the blocks gradually turn from blue to yellow. Examine the blocks regularly. Record how long it takes for each block to turn completely yellow.

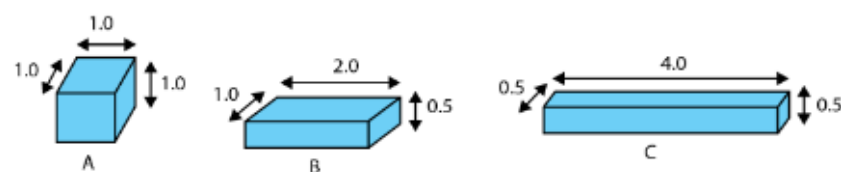


Figure 2.10 Three agar blocks with the same volume but different surface area



Link

Practical Workbook
 Experiment 2A

Observation and Discussion

- 1 What can you say about the relationship between surface area-to-volume ratio and the rate of absorption of the acid?
- 2 How can you relate the shape of the agar blocks to cells in the body?

Now, look at Figure 2.11. What do you notice? What do you think is taking place? Comment on the statements made by the three persons about the movement of molecules.

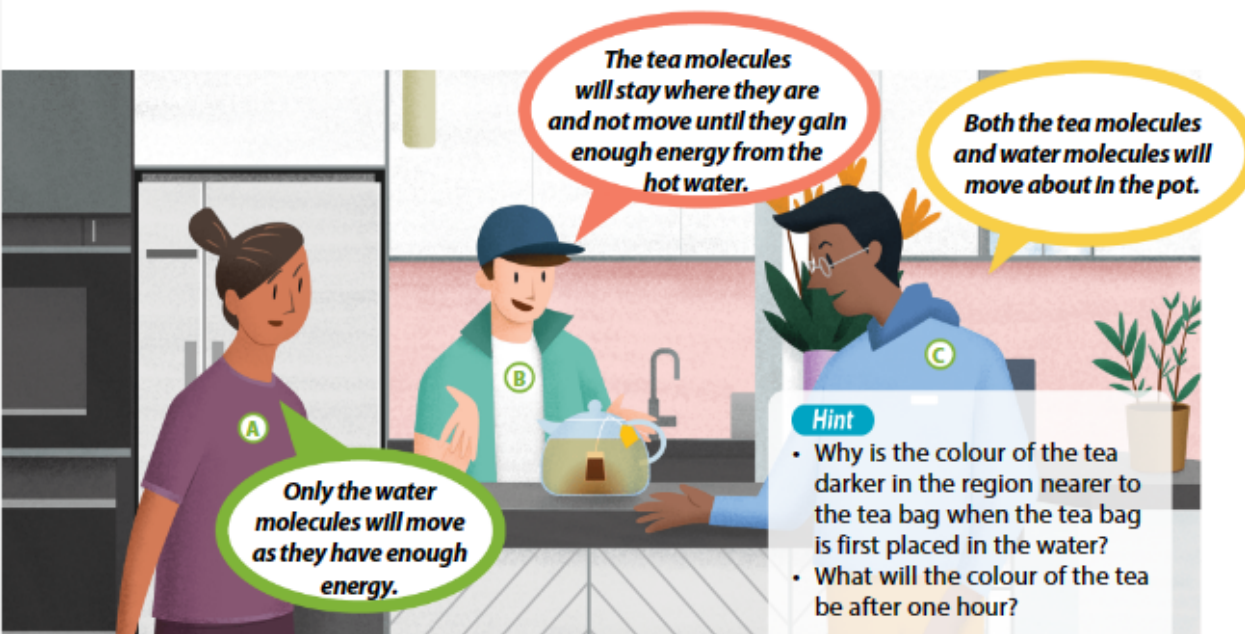


Figure 2.11 Three persons are discussing the movement of molecules. Comment on their statements.



Link

Chemistry

We learn that moving particles have kinetic energy. As temperature increases, particles gain more energy and move faster. The rate of diffusion increases as the temperature of the solution increases.

Let's Practise 2.1

- 1 (a) What is a concentration gradient?
(b) Define the term *diffusion*. What factor(s) affect the rate of diffusion?
- 2 Explain why actively growing cells are usually small in size. Why do cells **not** grow beyond a certain size?
- 3 (a) How are the root hair cell (Figure 2.12), the epithelial cell of the small intestine (Figure 2.13) and the red blood cell (Figure 2.14) adapted for absorption of materials?

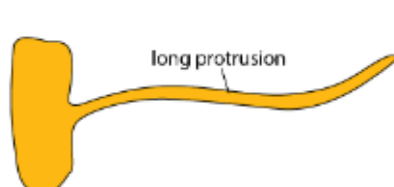


Figure 2.12 Root hair cell

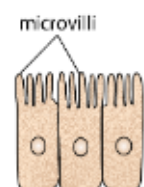


Figure 2.13 Epithelial cell

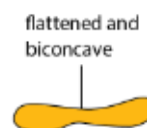


Figure 2.14 Red blood cell

- (b) What feature(s) do the three cells have in common?



Link

Theory Workbook
Worksheet 2A

2.2 What Is Osmosis?

Learning Outcomes

- Define osmosis, investigate and describe the effects of osmosis on plant and animal tissues.
- Discuss the factors that affect the rate of osmosis.

Osmosis

The cell membrane is a **partially permeable membrane**. It allows some substances to pass through but not others. Figure 2.15 shows the two arms of a U-tube separated by a partially permeable membrane. This membrane is permeable to water molecules but not to sucrose molecules. Sucrose is cane sugar, also known as table sugar.

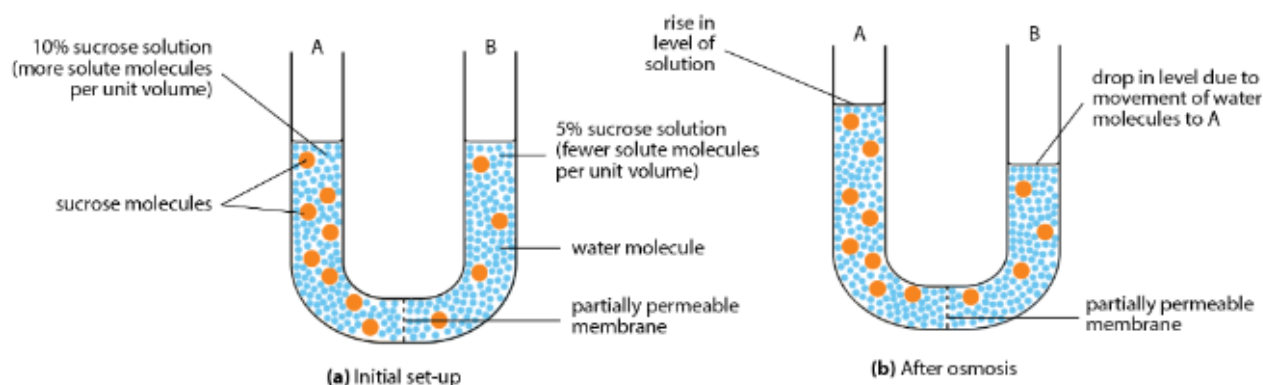


Figure 2.15 Experimental set-up to demonstrate osmosis

Compared to arm B, arm A contains:

- More sucrose molecules per unit volume
- Fewer water molecules per unit volume

After some time, the level of solution in arm A rises, while that in arm B falls.

What do you think has happened?

- Sucrose molecules cannot diffuse from arm A to B because the molecules are too big to pass through the pores of the membrane.
- Water molecules move from B to A because solution B has more water molecules per unit volume than solution A. A dilute solution has more water molecules per unit volume than a concentrated solution of the same volume.

Net result: Both arms A and B have the same solute concentration (*same number of solute molecules per unit volume*).

The diffusion of water molecules across a partially permeable membrane is called *osmosis*.



Link

Chemistry

We learn that the concentration of a solution is given by the amount of a solute dissolved in a unit volume of the solution.

Let's Investigate 2.4

Aim

To demonstrate osmosis

Procedure

- 1 Tie a knot at one end of a piece of dialysis tubing.
- 2 Half-fill a boiling tube with distilled water.
- 3 Use a pipette to half-fill the dialysis tubing with sucrose solution. Carefully rinse the outside of the dialysis tubing with distilled water if any sucrose solution is spilled.
- 4 Set up the apparatus as shown in Figure 2.16. Make sure the levels of the liquid inside and outside the tubing are the same. Use a paper clip to hold the dialysis tubing in place. Mark the level on the outside of the boiling tube.
- 5 Set up a second experiment in a similar way but with distilled water in both the dialysis tubing and the boiling tube.
- 6 After 20 minutes, observe and note the level of liquid inside and outside the tubing in each experiment.

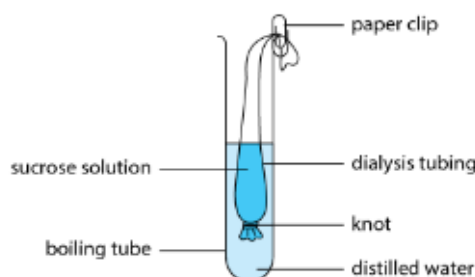


Figure 2.16 Experimental set-up to demonstrate osmosis

Observation and Discussion

- 1 What can you say about the dialysis tubing? How do you account for your observation in step 6?
- 2 What is the purpose of the second experimental set-up?



Link

Practical Workbook
Experiment 2B

What Is Water Potential and How Is It Related to Osmosis?

- The term '**water potential**' is always used in connection with osmosis. *Water potential is a measure of the tendency of water molecules to move from one place to another. A dilute solution (solution with lower concentration of solute) would have a higher water potential than a concentrated solution. Hence, water molecules would move out of the dilute solution and into the concentrated solution through osmosis.*
- When a partially permeable membrane separates two solutions of different water potentials, a water potential gradient is established (Figure 2.17). Water molecules move from a region with higher water potential to a region with a lower one, that is, down a water potential gradient.

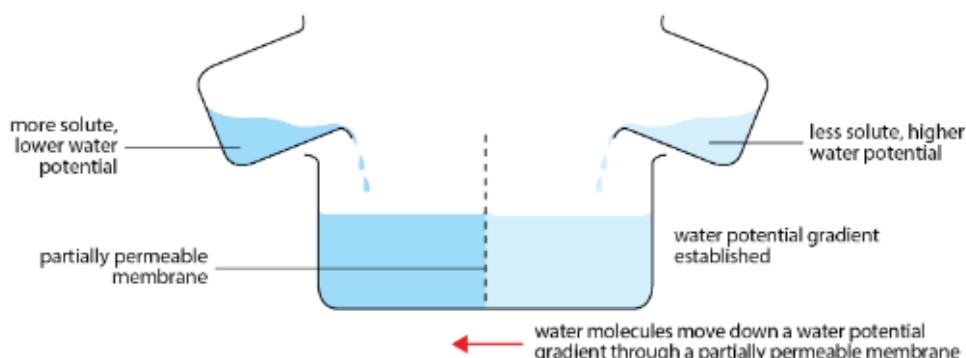


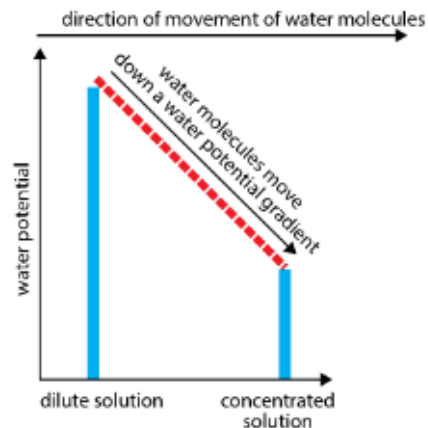
Figure 2.17 Water potential gradient set up in the container



Figure 2.18 represents graphically how water potential is associated with osmosis.

Osmosis is the net movement of water molecules from a region of higher water potential to a region of lower water potential, through a partially permeable membrane.

Figure 2.18 Graphical representation of water potential gradient



Tech Connect

In Singapore, there are five NEWater plants that supply Singapore with up to 40% of its water needs.

The NEWater process involves recycling treated used water into ultra-clean, high-grade reclaimed water. One of the stages of the NEWater production process is reverse osmosis. Similar to osmosis, this process involves a partially permeable membrane. However, pressure is applied to move water molecules across the membrane in a direction that is opposite to that of osmosis.



Figure 2.19 Reverse osmosis water treatment system

Reverse osmosis can remove toxins from water. By this method, very small particles can be removed by using an electric pump to force water under high pressure through a membrane (Figure 2.19). The membrane is partially permeable and has very tiny pores, which allow only very small molecules such as water molecules to pass through. The water is passed through the membrane several times until pure water is obtained.

Why do you think NEWater is an important source of water for Singapore?

Similar to diffusion, the rate of osmosis can be affected by factors such as:

- water potential gradient
- distance over which water molecules need to move
- surface area-to-volume ratio

How Does Osmosis Affect Living Organisms?

A cell is surrounded by a living, partially permeable cell membrane. Enclosed within the cell membrane are the nucleus, cytoplasm and a mixture of various substances.

Note that the cell wall of plants is permeable and allows most dissolved substances to pass through. A plant cell behaves differently from an animal cell when placed in solutions with differing water potentials. This is due to the presence of the cell wall in plant cells.

What Happens to a Cell in a Solution With Higher Water Potential?

When a cell is placed in a solution with a higher water potential, water molecules will move from a region of higher water potential (outside the cell), into a region of lower water potential (inside the cell).

A plant cell will expand or swell. This is because plant cells are protected by an inelastic cell wall (Figure 2.20). Plants are supported by the pressure of water inside the cells pressing outwards on the cell wall.

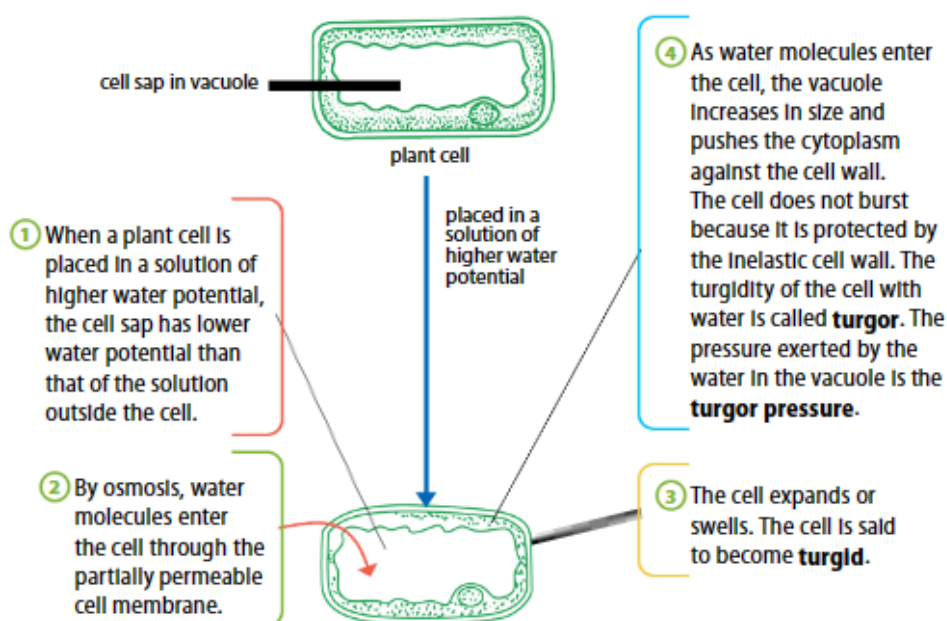


Figure 2.20 A plant cell in a solution with higher water potential

An animal cell will swell and may even burst in a solution of higher water potential than its cytoplasm (Figure 2.21). This is because, unlike plants, it does not have a cell wall to protect it.

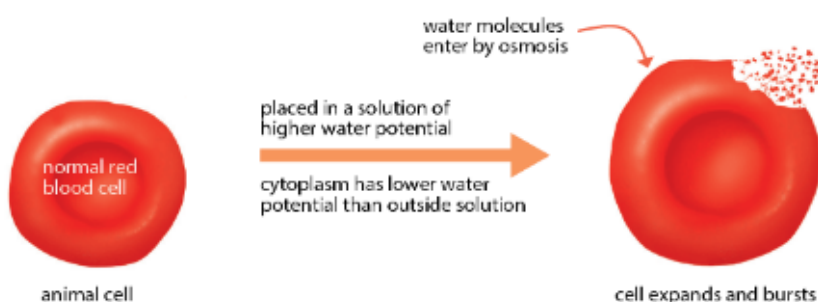


Figure 2.21 An animal cell in a solution with higher water potential

What Happens to a Cell in a Solution of the Same Water Potential?

Cells immersed in a solution with the same water potential as their cytoplasm will not change their size or shape. The movement of water molecules is the same in both directions. Hence, there is no net movement of water molecules in or out of the cell.



Link

Human cells must be surrounded by fluid in relatively constant water potential. Read more about how this is done in Chapter 9.



Disciplinary Idea Homeostasis, Co-ordination and Response

Through the processes of diffusion, osmosis and active transport, the internal environments of living organisms are kept constant to provide the optimal conditions for cells to survive.



What Happens to a Cell in a Solution With Lower Water Potential?

When a cell is placed in a solution with a lower water potential, water molecules will move from a region of higher water potential (inside the cell), into a region of lower water potential (outside the cell).

A plant cell will decrease in size and become limp (Figure 2.22).

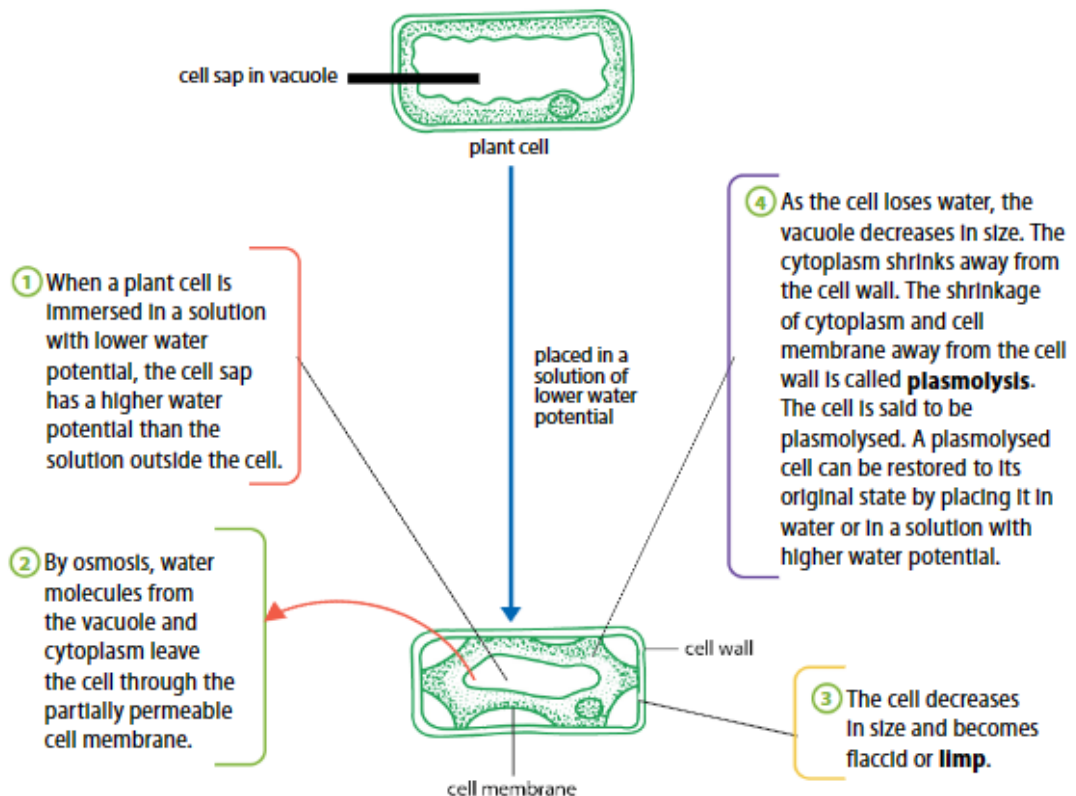


Figure 2.22 A plant cell in a solution with lower water potential

Placing an animal cell in a solution with lower water potential will cause it to lose water. The cell shrinks and spikes appear on the cell (Figure 2.23). This process is called **crenation**. An animal cell will become dehydrated and eventually die when placed in a solution with a low water potential.

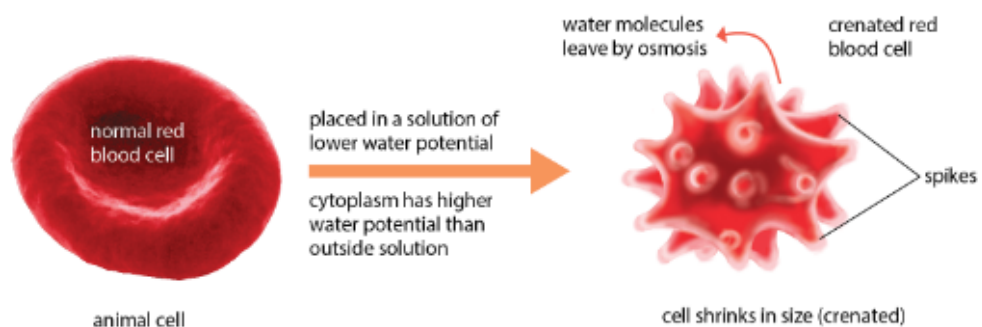


Figure 2.23 An animal cell in a solution with lower water potential

Why Is Turgor Important in Plants?

Turgor, or how turgid cells are, plays an important role in maintaining the shape of soft tissues in plants. The young stems and leaves of herbaceous and non-woody plants are able to remain firm and erect. This is because of the turgor pressure within their cells. When there is a high rate of water loss from the cells, they lose their turgidity and the plant wilts.

The movements of certain plant parts are due to changes in turgor. For example, changes in the turgor of the guard cells cause the opening and closing of the stomata (Figure 2.24).

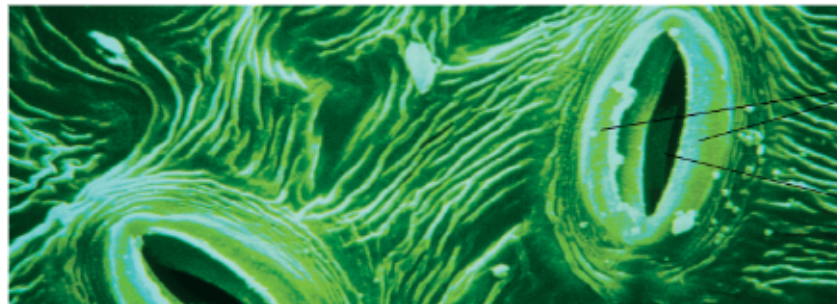


Figure 2.24 Electron micrograph of stomata



Link

How do the stomata of plants open and close? Read more about it in Chapter 12.

turgor in guard cells causes stoma to open

stoma

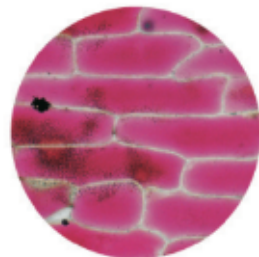


Helpful Note

Soil solution is a thin film of water that surrounds individual soil particles. It usually contains dissolved mineral salts or ions.

Plasmolysis causes cells to become flaccid or limp (Figure 2.25). Cells will be killed if they remain plasmolysed for too long. Thus, it is not advisable to add too much fertiliser around the roots of plants because the soil solution will become very concentrated and water molecules will move out of the roots by osmosis.

Inability of the roots to absorb water, together with continued evaporation of water from the leaves, will cause the plant to wilt. Unless sufficient water is added to dilute the soil solution, the plant will eventually die (Figure 2.26).



(a) Turgid plant cells



(b) Flaccid and plasmolysed plant cells

Figure 2.25 Cells of onion leaf epidermis (stained)



(a) Turgor pressure in the cells of the plant helps to keep this plant firm and upright.

(b) Loss of turgor due to excessive water loss may cause a plant to wilt.

Figure 2.26 Effects of turgor pressure on plants



Link

Practical Workbook
Experiment 2C

Let's Investigate 2.5

How can we show osmosis in living tissues (potato)?

Potato strips are commonly used in experiments to show osmosis in living tissues. The dimensions of the strips used are shown in Figure 2.27. For instructions on how to set up this experiment, refer to Experiment 2C of the Practical Workbook.

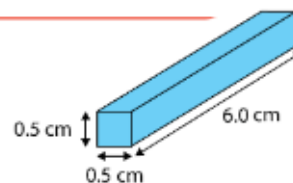


Figure 2.27 A potato strip used in osmosis experiments

If the potato strips decrease in length, does this relate to water molecules leaving the strips? How can this experiment be extended to estimate the concentration of cell sap in the cell?



Word Alert

Cuticle: a thin protective outermost layer



Link

Practical Workbook
Experiment 2D

Let's Investigate 2.6

How can we show osmosis in living tissues (scape)?

A scape (leafless flower stalk), e.g. Chinese leek, can also be used to demonstrate osmosis in living tissue. Figure 2.28(a) shows a section of a scape. A scape has two main layers of cells; the outer epidermal cells and the cortical cells. Only the outer epidermal cells are covered by a waterproof cuticle that protects the plant tissue against water loss.

One cut strip is placed in water and another in concentrated sucrose solution (Figure 2.28(b)).

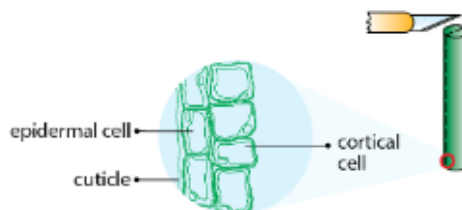


Figure 2.28(a) Layers of cells in a scape

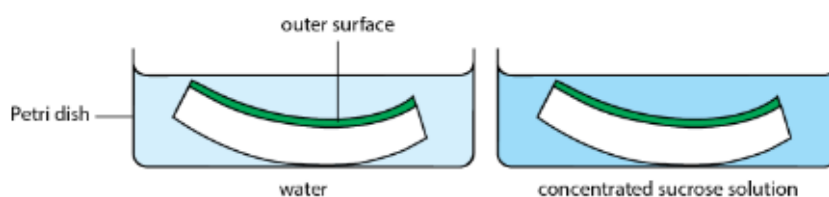


Figure 2.28(b) Cut scape in water and a concentrated solution

Predict what happens to the strip in each solution. Carry out Experiment 2D in the Practical Workbook to find out more.

Let's Investigate 2.7

You are given an experiment to determine the relative concentrations of three sugar solutions A, B and C. You are provided with a spinach stem, 3 cm long, and a scalpel/sharp knife.

1 The problem

How to determine the relative concentrations of the three solutions

2 Some points to consider

- The different water potentials of the solutions
- The water potential of cell sap
- The skin (epidermis) of the plant material is waterproof.
- Water molecules move from a solution of higher water potential to a solution of lower water potential.

3 Method

Describe how you would carry out your investigation.

4 Results

Enter your results/observations (including any drawings) below:

Solution A	Solution B	Solution C

5 Determine the relative concentrations of the solutions.

Relative Concentration	Very Dilute	Dilute	Very Concentrated
Solution A			
Solution B			
Solution C			

(Put a tick in the appropriate box.)

6 Explain your answer.

Table 2.2 summarises the key differences between diffusion and osmosis.

Table 2.2 Differences between diffusion and osmosis

Diffusion	Osmosis
Net movement of particles (atoms, molecules, ions)	Net movement of water molecules
Movement of particles from a region of higher concentration to a region of lower concentration, down a concentration gradient	Movement of water molecules from a solution of higher water potential to a solution of lower water potential, down a water potential gradient
Partially permeable membrane not required	Partially permeable membrane required



Let's Practise 2.2

- 1 Humans store food to see them through times when food is in short supply. Unfortunately, bacteria and fungi attack stored food and make it go bad. One way of preventing this is to store food in strong salt solutions (brine) or sugar solutions (syrops) (Figure 2.29). Suggest with reasons why brine or syrups are used in food preservation.
- 2 An animal cell is placed in a concentrated solution of sugar. Which substance will leave the cell and which will move into the cell? What processes are involved?



Figure 2.29



Link

Theory Workbook
Worksheet 2B



Disciplinary Idea

Energy

Energy is required during active transport to ensure that substances can be transported against a concentration gradient, which is critical for many biological processes.

2.3 What Is Active Transport?

Learning Outcome

- Define active transport and discuss its importance as an energy-consuming process by which substances are transported against a concentration gradient, as in ion uptake by root hairs and uptake of glucose by cells in the villi.

Living cells are able to absorb certain substances even though these substances are of higher concentration inside the cell than they are in the external environment. This means that the cells are absorbing substances against a concentration gradient (Figure 2.30). Such a process requires energy and is called *active transport*.

- **Active transport** is the process in which energy is used to move the particles of a substance across a membrane against its concentration gradient, that is, from a region where the particles are of lower concentration to a region where they are of higher concentration.

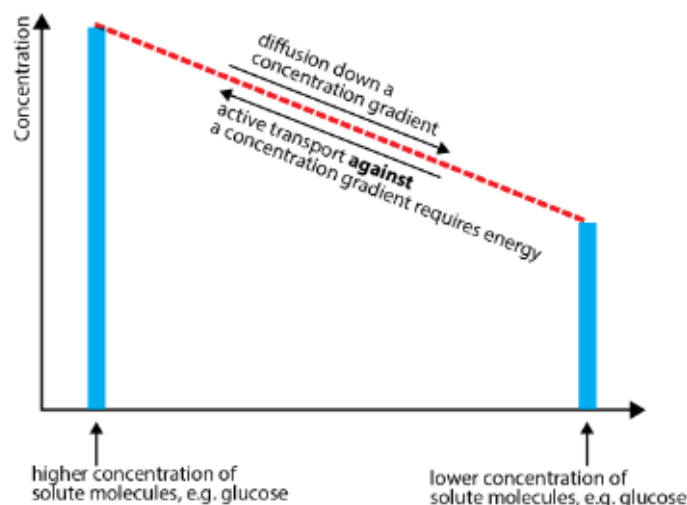


Figure 2.30 Difference between active transport and diffusion

Table 2.3 summarises the key differences between diffusion and active transport.

Table 2.3 Differences between diffusion and active transport

Diffusion	Active Transport
Net movement of particles from a region of higher concentration to a region of lower concentration, down a concentration gradient	Net movement of particles from a region of lower concentration to a region of higher concentration, against a concentration gradient
Energy from respiration not required	Energy from respiration required
Cell membrane not required	Cell membrane required



Link

How do cells of the small intestine carry out nutrient uptake? Read Chapter 5 to find out.

Why is active transport an important process in the kidneys? Read more about it in Chapter 8.

How do root hair cells carry out the uptake of mineral salts? Read Chapter 12 to answer the question.

Where Does Active Transport Occur?

Active transport occurs only in living cells because living cells respire. It is during respiration that energy is released, and part of this energy is used in active transport.

In the human body, examples of active transport include the uptake of glucose by the microvilli of epithelial cells in the small intestine, and from the kidney tubules into the blood capillaries.

In plants, root hair cells can take in mineral salts from the soil solution by diffusion or active transport, depending on the concentration of mineral salts in the soil solution (Figure 2.31).

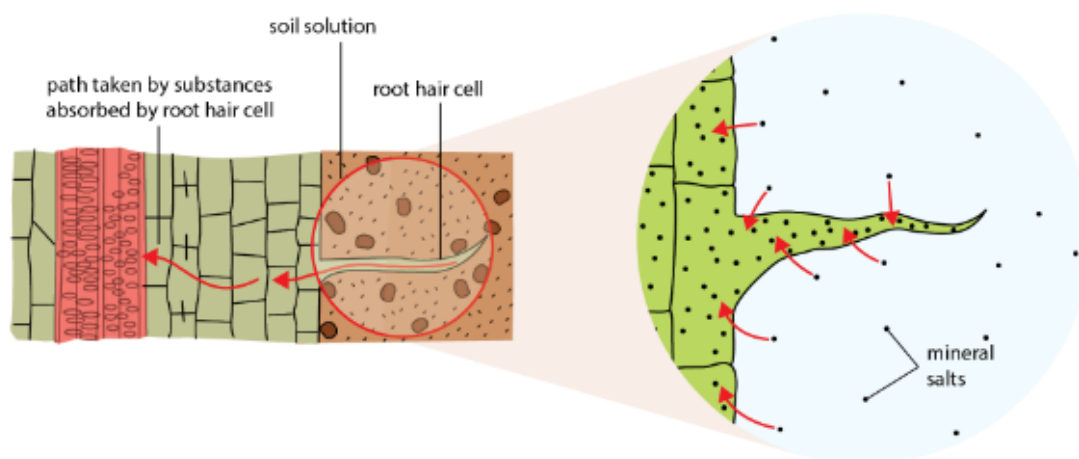


Figure 2.31 Root hair cells take in dissolved mineral salts through diffusion as well as active transport.

Mineral salts can enter the root hair cell, against the concentration gradient



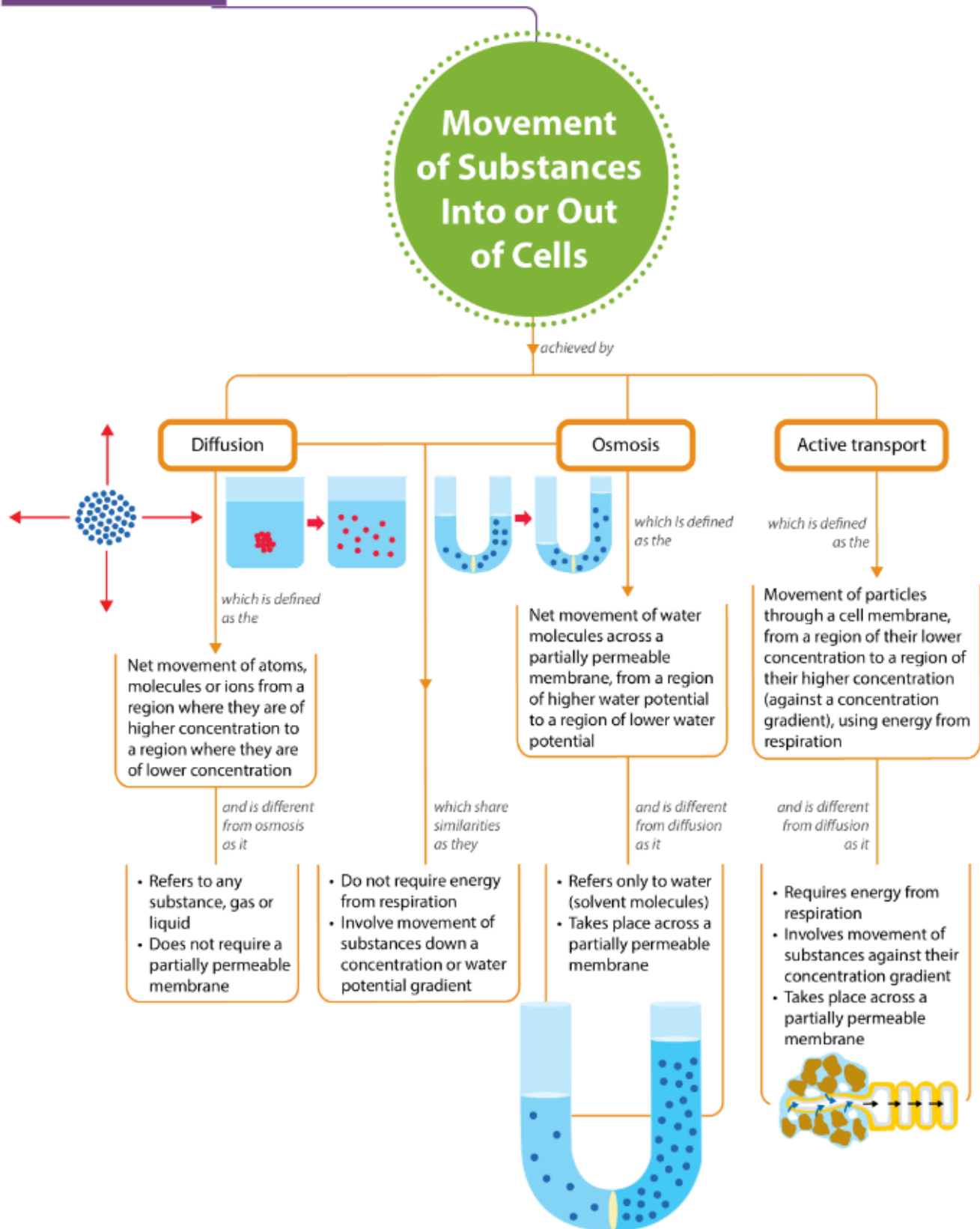
Link

Theory Workbook
Worksheet 2C
Let's Assess
Let's Reflect

Let's Practise 2.3

- 1 Why does active transport **not** take place in dead cells?
- 2 Name **three** characteristics that are different between diffusion and active transport.

Let's Map It



Let's Review

Section A: Multiple-choice Questions

- 1 Strips of potato tissue were placed in sugar solutions of different concentrations. The percentage change in length of the potato strips is shown in the graph in Figure 2.32.

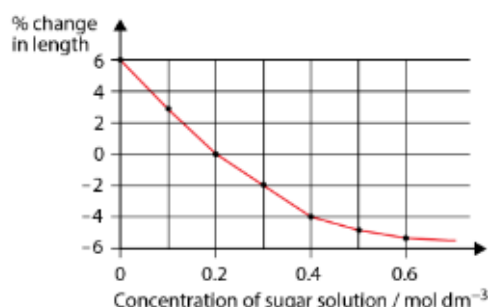


Figure 2.32

Which solution has the same water potential as the cell sap?

- ☐ A 0.05 mol dm⁻³ ☐ B 0.1 mol dm⁻³
☐ C 0.2 mol dm⁻³ ☐ D 0.4 mol dm⁻³

- 2 An apparatus was set up as shown in Figure 2.33. After a few hours, the level of solution in the thistle funnel rose. The water in the beaker turned red.

Which process caused the water in the beaker to turn red?

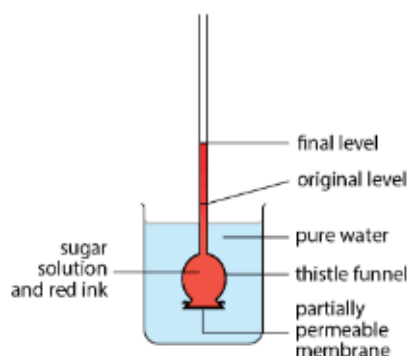


Figure 2.33

- ☐ A active transport
☐ B diffusion
☐ C gravitational pull
☐ D osmosis

Section B: Structured Question

- 1 Arrange set-ups X, Y and Z in decreasing order of their water potential gradients between sucrose solutions A, B, C and D in the beakers shown in Figure 2.34.

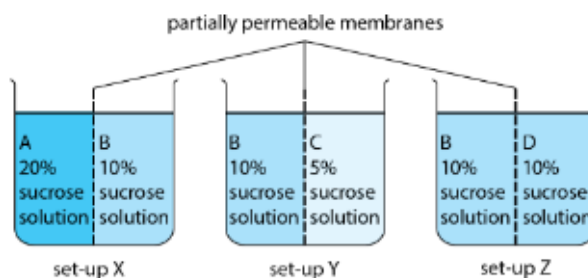


Figure 2.34

Section C: Free-response Questions

- 1 Define the terms *diffusion*, *osmosis* and *partially permeable membrane*.
- 2 How does diffusion differ from osmosis?
- 3 Why do sports drinks have the same water potential as the cells in our body? Suggest what would happen if body cells were in an environment that had:
 - (a) significantly higher water potential;
 - (b) significantly lower water potential.

CHAPTER

03

Biological Molecules



What You Will Learn



- What are carbohydrates?
- What are fats?
- What are proteins?

Do you know that marathon runners need to eat a lot of carbohydrates two days before a race? This may include sugary foods. We know that eating too much sugary foods can cause obesity, sometimes even for people who exercise regularly. Why do you think marathon runners still eat these foods?



3.1 What Are Carbohydrates?

Learning Outcomes

- List the chemical elements that make up carbohydrates.
- State that cellulose, glycogen and starch are synthesised from glucose.
- State the main role of carbohydrates as an immediate source of energy in living organisms.
- Describe and carry out tests for starch (using iodine in potassium iodide solution) and reducing sugars (using Benedict's solution).

The Need for Food and Water

All living organisms need food. The food we eat contains nutrients that are essential for us. Nutrients include water, carbohydrates, fats and proteins. Carbohydrates, fats and proteins are three major types of biological molecules found in living organisms. Water is an essential component of all body tissues. About 70% of our body weight is water. Hence, water is extremely important to life.

Carbohydrates

Figure 3.1 shows food rich in carbohydrates.

Carbohydrates are organic molecules made up of the elements carbon, hydrogen and oxygen. The hydrogen and oxygen atoms are present in the ratio 2 : 1.

For example:

- glucose has the formula $C_6H_{12}O_6$ (ratio of hydrogen to oxygen is $12H : 6O = 2H : 1O$)
- sucrose (cane sugar) has the formula $C_{12}H_{22}O_{11}$ (ratio of hydrogen to oxygen is $22H : 11O = 2H : 1O$)

Carbohydrates may be classified as single sugars, double sugars or complex carbohydrates (Figure 3.2).



Helpful Note

Water has several important functions. It dissolves substances for chemical reactions that take place in living things. In plants, water is essential for photosynthesis, to keep cells turgid or firm, and to transport mineral salts. In humans, water helps to regulate body temperature and transport dissolved substances within the body. Drinking enough water is important for various body functions.

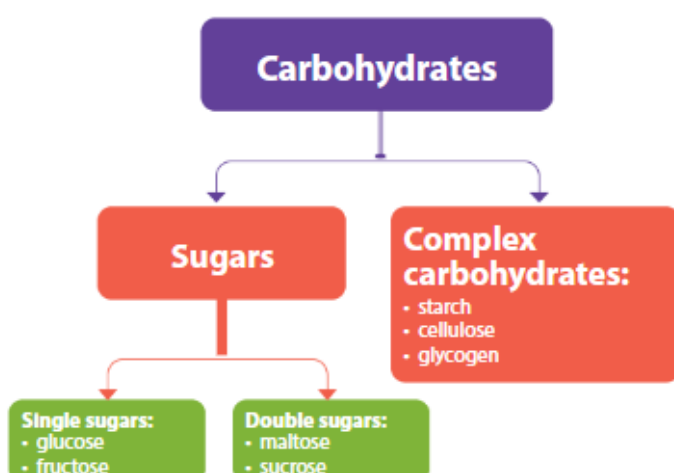


Figure 3.1 Food rich in carbohydrates

Figure 3.2 Classification of carbohydrates



Link

What is water potential?
Recall what you have
learnt in Chapter 2.

Sugars

Sugars are sweet and soluble in water. When dissolved in water, they will lower the water potential of the solution. Sugars provide us with energy to do work and carry out activities (Figure 3.3).



Figure 3.3 Sugars provide us with energy to do sports.

Single Sugars

A single sugar is the basic unit of carbohydrate. It can pass through cell membranes and be absorbed into the cells.

The common single sugars are **glucose** and **fructose** (refer to Table 3.1). They both have the same chemical formula, $C_6H_{12}O_6$, but their atoms are arranged differently within the molecules. These different arrangements give the sugars different chemical and biological properties.

Table 3.1 Occurrence of single sugars

Single Sugar	Occurrence
Glucose	Found in plants and animals
Fructose	Common in plants, but rare in animals

Glucose is found in plants and animals. Fructose is common in plants but rare in animals. The structure of glucose and fructose can be represented by the diagrams shown in Figure 3.4.

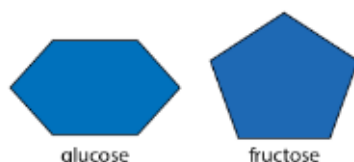


Figure 3.4 Structures of glucose and fructose

Double Sugars

A double sugar is formed when two single sugars are joined together. Common double sugars are **maltose** and **sucrose**.

Maltose (malt sugar) occurs in germinating grains. Maltose consists of two glucose molecules bonded together.

The equation below shows how a maltose molecule can be produced from two glucose molecules.



A sucrose molecule is made up of one glucose molecule and one fructose molecule joined together.



The structure of sucrose can be represented in a diagram as shown in Figure 3.5.



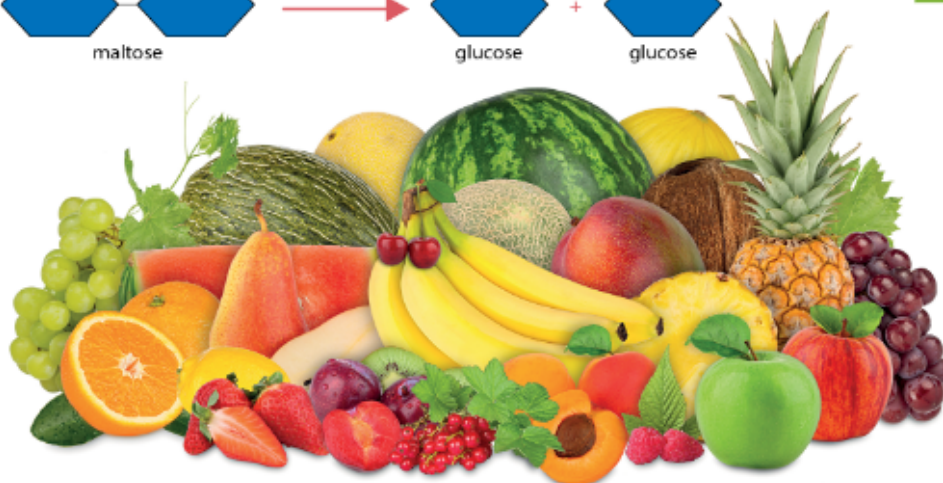
Figure 3.5 Structure of sucrose

A double sugar can be split into two single sugar molecules by using an organic molecule called an enzyme. For example, when a solution of maltose is mixed with the enzyme maltase, glucose molecules are produced.



Link

What are enzymes?
Read more about
them in Chapter 4.





Link

Chemistry

We learn that a redox reaction is a chemical reaction which involves the oxidation of a substance and the reduction of another substance.



Helpful Note

For a solid food sample, e.g. a peanut, break the sample up to release the cell contents. This can be done by crushing the sample in water using a mortar and pestle. The sample can then be tested.



Link

Practical Workbook
Experiment 3A

How Can We Test for Reducing Sugars?

Glucose, fructose and maltose are also known as **reducing sugars**. Reducing sugars will produce a red precipitate when boiled with Benedict's solution (refer to Let's Investigate 3.1). Sucrose is a non-reducing sugar and will not give a red precipitate with this test.

Let's Investigate 3.1

Aim

To test for the presence of reducing sugars in different food samples using Benedict's solution

Procedure

- 1 Place 2 cm³ of each food sample into a test-tube (Figure 3.6).
- 2 Add 2 cm³ of Benedict's solution to the food sample (Figure 3.7).
- 3 Shake the mixture and place the test-tube in a boiling water-bath for 2–3 minutes (Figure 3.8).
- 4 Record the colour of the solution.

Observation

Table 3.2 shows the colour changes observed when carrying out the Benedict's test with increasing amounts of reducing sugar.

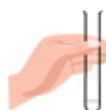


Figure 3.6



Figure 3.7

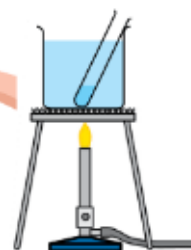


Figure 3.8

Table 3.2 Colour changes with different amounts of reducing sugar

Observation	Amount Present
Solution remained blue	No reducing sugar
Benedict's solution turned from blue to green	Traces of reducing sugar
Benedict's solution turned from blue to yellow or orange	Moderate amount of reducing sugar
Benedict's solution turned from blue to red / Red precipitate formed	Large amount of reducing sugar

Figure 3.9 shows the colour change from blue to red indicating an increasing amount of reducing sugar present in the solutions.



Figure 3.9

Complex Carbohydrates

What Are Complex Carbohydrates?

A complex carbohydrate is made up of many similar molecules of single sugar joined together to form a large molecule.

Starch, glycogen and cellulose are complex carbohydrates made up of numerous glucose molecules. The glucose molecules are linked in different ways, giving rise to different structures. Hence, starch, glycogen and cellulose have different chemical and biological properties. They also have different roles as shown in Table 3.3.

Table 3.3 Types of complex carbohydrates

Complex Carbohydrate	Structure	Role	Occurrence
Starch	A starch molecule is made up of several thousand glucose molecules joined together.	It is a storage form of carbohydrates in plants. When needed, it can be digested to glucose to provide energy for cell activities.	Found in storage organs of plants, e.g. potato tubers and tapioca
Cellulose	A cellulose molecule is made up of many glucose molecules joined together. The bonds between glucose units are different from that in starch.	The cellulose cell wall protects plant cells from bursting or damage. Cellulose cannot be digested in our intestines. They serve as <i>dietary fibre</i> that prevents constipation.	Present in cell walls of plants
Glycogen	Glycogen is a branched molecule. It is made up of many glucose molecules joined together.	It is a storage form of carbohydrates in mammals. When needed, it is digested to glucose to provide energy for cell activities.	Stored in the liver and muscles of mammals



Link

Chemistry

We learn that a polymer is a type of macromolecule formed by many small units called monomers linked together.



Helpful Note

Complex carbohydrates such as starch, cellulose and glycogen have different structures (Figure 3.10).

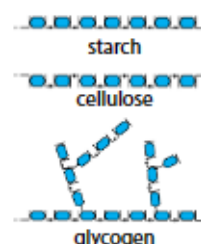


Figure 3.10



Tech Connect

Fibre is found in vegetables and fruits. Fibre cannot be digested and we often find food high in fibre difficult to chew. This poses a problem for the elderly, who may not be able to chew food effectively.

Enter the technology of soluble fibre supplements! Engineers have applied their knowledge of what roughage can do for our digestive system. They also understand how roughage can exist as fibres that are soluble in water. The result of this is a powdery substance that we can dissolve in water, or even mix with food or with soup and drink down (Figure 3.11). Some supplements are tasteless and odourless, which makes them highly suitable for the taste-conscious consumer.

This is a good example of how engineers create a piece of technology out of what was originally a solution to a problem. The technology comes in the form of an industrial product that is available to the average consumer.



Figure 3.11 Supplement powders of chlorella, wheatgrass and moringa leaf



Disciplinary Idea

Energy

Complex carbohydrates are one of the energy stores used by plants and animals.

Glycogen and Starch Are Stores of Glucose

Plants store glucose in the form of starch. Animals cannot make or store starch in their bodies. We get most of our carbohydrates from plants in the form of starch.

In animals, the main store of glucose is glycogen. Hence, glycogen is sometimes called 'animal starch'. In mammals, glycogen is stored mainly in the liver and the muscles (Figure 3.12).

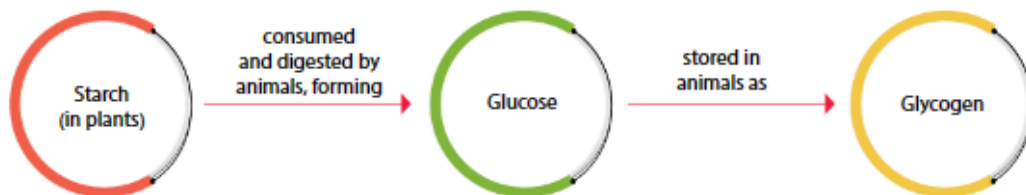


Figure 3.12 Glycogen and starch as stores of glucose

Glycogen and starch are suitable as storage materials in cells because:

- They are insoluble in water, so they do not change the water potential in the cells.
- They are large molecules that cannot diffuse through cell membranes, so they will not be lost from the cell.
- They can easily be broken down to glucose when needed, for example, in tissue respiration.
- Their molecules have compact shapes, so they occupy less space than all the individual glucose molecules that make up a glycogen or starch molecule.



Link

How is starch broken down in the gut? Read about it in Chapter 5.

Breakdown of Starch

Starch in the foods we eat may be digested in our alimentary canal. When starch is digested, the bonds within the polysaccharide are broken and the glucose molecules are released.

The enzyme amylase digests starch to form the sugar maltose. Amylase cannot break maltose down to glucose. Maltose is hydrolysed to glucose by another enzyme, maltase. Note that complete digestion of starch gives glucose molecules (Figure 3.13).

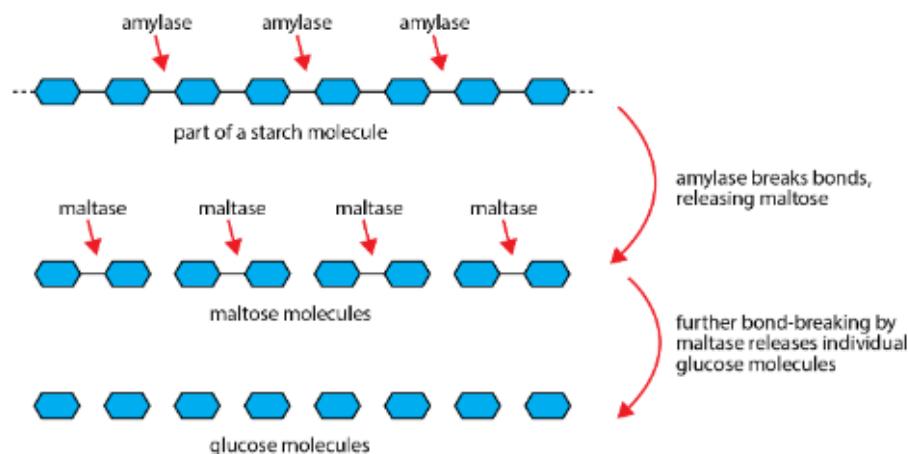


Figure 3.13 Digestion of starch



What Are the Functions of Carbohydrates?

Carbohydrates are needed:

- as a substrate for respiration, to provide energy for cell activities;
- to form supporting structures, for example, cell walls in plants;
- to be converted into other organic compounds such as amino acids and fats;
- for the formation of nucleic acids, for example, DNA;
- to synthesise lubricants, for example, mucus, which consists of a carbohydrate and a protein; and
- to synthesise the nectar in some flowers. **Nectar** is a sweet liquid that plants produce to attract insects.



Link

What is respiration? How are carbohydrates involved in the formation of DNA? Read more about these in Chapters 7 and 14 respectively.

How Can We Test for Starch?

Starch can be detected by the iodine test. A few drops of *iodine solution* to any substance containing starch will produce a blue-black colour.

Let's Investigate 3.2

Aim

To test for the presence of starch in a food sample using iodine solution

Procedure

- 1 Add a few drops of iodine in potassium iodide solution to a food sample.
- 2 Record your observations.

Observation

Iodine solution on the potato turns from brown to blue-black upon contact with starch in the food sample (Figure 3.14).



Figure 3.14 Iodine solution on the food sample turns from brown to blue-black.



Link

Practical Workbook
Experiment 3A

Let's Practise 3.1

- 1 Describe how you would test for reducing sugars in a food sample.
- 2 Describe how you would test for starch in a food sample.
- 3 Outline the role of carbohydrates in the life of an organism.
- 4 What do you think will happen if you add some amylase to a starch solution and test the resulting solution with Benedict's solution after five minutes?

3.2 What Are Fats?

Learning Outcomes

- List the chemical elements that make up fats.
- State that lipids such as fats are synthesised from glycerol and fatty acids.
- State the main roles of fats for insulation and long-term storage of energy in living organisms.
- Describe and carry out tests for fats (using ethanol).

Have you ever put a bowl or pot of soup in the refrigerator and seen the oil on the surface harden into solids? These are oils or fats (Figure 3.15). Where do they come from, and what does the body do with them?

Fats

Fats are a type of lipid.

Fats, like carbohydrates, are organic molecules made up of the elements carbon, hydrogen and oxygen. But unlike carbohydrates, fats contain much less oxygen in proportion to hydrogen.

For example, tristearin (beef fat) has the formula $C_{57}H_{110}O_6$. Note how little oxygen it contains in proportion to hydrogen. *The proportions of the elements that make up fats are not fixed, so there is no general formula for fats.*

Fats can be animal fats or plant fats. Fats are commonly used as a store of energy, especially by animals.

Fats Can Be Broken Down into Fatty Acids and Glycerol

Fats can be broken down into simpler compounds such as fatty acids and glycerol. Refer to the general equation shown in Figure 3.16.



Figure 3.16 A fat molecule breaks down into glycerol and fatty acid.

The reaction involves an enzyme. For example, when tristearin is broken down by the enzyme lipase, stearic acid and glycerol are produced:

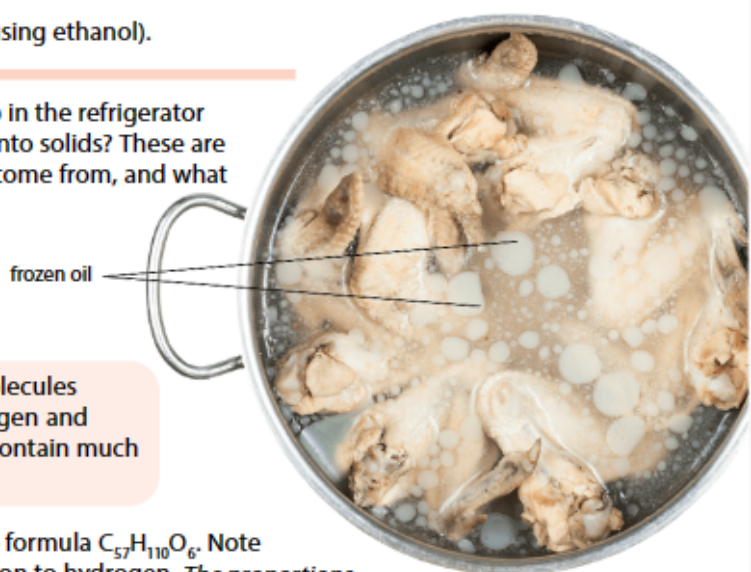
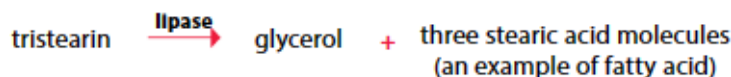


Figure 3.15 The oil on the surface changes from liquid to solid when placed in the refrigerator.



What Are the Sources of Fats?

- Foods that are rich in fats include butter, cheese, fatty meat, olives, many nuts, peas, beans, seeds of castor oil and palm oil (Figure 3.17).
- The meat of most fishes and 'white meats' have relatively less fats. However, some fishes such as herring and salmon have lots of fats.



Figure 3.17 Examples of food rich in fats

What Are the Functions of Fats?

How are some animals able to survive in cold climate, while others are not able to? What are the features common to these animals? How do these features help them to survive in the cold?

Fats function as:

- A source and a long-term storage of energy.
 - They are a suitable long-term storage material because fats have a higher energy value compared to carbohydrates.
- An insulating material that prevents excessive heat loss. For example, animals such as seals have a thick layer of fat (blubber) beneath the skin, which helps to reduce loss of body heat (Figure 3.18).
- A solvent for fat-soluble vitamins and many other vital substances such as hormones.
- An essential part of cells, especially in cell membranes.
- A way to reduce water loss from the skin surface. Glands in the skin secrete an oily substance.
 - This oily substance forms a thin layer over the skin surface, reducing the rate of evaporation of water.
 - The oily substance also reduces the rate of heat loss from the skin.

Figure 3.18 Seals and polar bears have a thick layer of fat beneath their skin, which helps reduce heat loss.



Disciplinary Idea

Energy

Fats are one of the energy stores of animals. They are required by living organisms to carry out life processes.



Link

How does the body control heat loss? Read more about it in Chapter 9.

How Can We Test for Fats?

The *ethanol emulsion test* is a test for the presence of fats. A white emulsion is formed when ethanol and water are added to fats. An *emulsion* is a suspension of small drops of a liquid in another liquid.

Let's Investigate 3.3

Aim

To test for the presence of fats in food samples using the ethanol emulsion test

Procedure

- 1 On samples in liquid state (e.g. coconut oil):
 - (a) Add 2 cm³ of ethanol to a drop of liquid sample in a test-tube and shake the mixture thoroughly.
 - (b) Add 2 cm³ of water to the mixture and shake the mixture.
 - (c) Record your observation.
- 2 On samples in solid state (e.g. peanut):
 - (a) Crush the solid sample into small pieces using a mortar and pestle and place the pieces in a test-tube.
 - (b) Add 2 cm³ of ethanol into the test-tube and shake thoroughly.
 - (c) Allow the solid particles to settle. Carefully decant the ethanol (pour off the top layer of ethanol) into another test-tube containing 2 cm³ of water and shake the mixture.
 - (d) Record your observation.

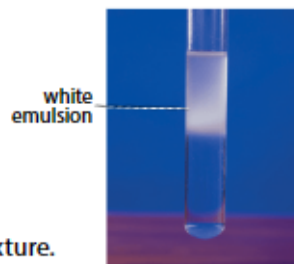


Figure 3.19 A white emulsion formed indicates the presence of fats. In the absence of fats, the solution will remain clear.

Observation

The white emulsion produced indicates the presence of fats (Figure 3.19).



Link

Practical Workbook
Experiment 3A

Let's Practise 3.2

- 1 List the chemical elements that make up fats.
- 2 List **three** functions of fats.
- 3 Describe how you would test for fats in a food sample.



Past to Present

How has our opinion of eating eggs changed over time? In the past, eggs were considered bad for our health and we were discouraged from eating more than two per week. Now, eggs are considered by some nutritionists as the "perfect food". They are believed to contain all the necessary nutrients that are good for our growth and maintenance of the body (Figure 3.20). Eggs also contain cholesterol, which is a type of lipid.

What about the discussion on cholesterol intake? Is the amount of cholesterol found in our blood determined by how much cholesterol we take in from food? Or is cholesterol manufactured by our bodies from other types of nutrients? Are all forms of cholesterol bad for our health?

Our knowledge of nutrients, and the roles they play in our lives, keeps maturing as we gain a better understanding of how our bodies function.

What attitudes should we embrace as we continue to explore this topic and discover more insights on food and nutrients? How should we behave when these insights from the latest research studies contradict what we thought we knew about the topic?



Figure 3.20 Eggs contain protein, healthy fats and many nutrients like vitamins A, D and E, iron and folate.

3.3 What Are Proteins?

Learning Outcomes

- List the chemical elements that make up proteins.
- State that polypeptides and protein are synthesised from amino acids.
- State the main roles of proteins for growth and repair of cells in living organisms.
- Describe and carry out tests for protein (using biuret solution).

Vegetarians are people who choose not to eat meat. Instead of consuming meat as a source of protein, they eat a lot more dairy (milk-based) or soy products. This is because proteins are essential nutrients and so alternative sources of protein must be consumed to ensure a healthy and balanced diet.

Proteins

- **Proteins** are organic molecules made up of the elements carbon, hydrogen, oxygen and nitrogen. Another element, sulfur, may also be present.

Proteins are always present in all cells. Their molecules are the largest and most complicated of all the food substances. Proteins are commonly found in the meat of animals (Figure 3.21).

Amino Acids — the Building Blocks of Proteins

A protein molecule is built up from simpler compounds known as amino acids. An *amino acid* is made up of an amino group ($-\text{NH}_2$), an acidic group ($-\text{COOH}$) and a *side chain* (denoted by R , which may sometimes contain sulfur). The general formula for an amino acid can be written as:

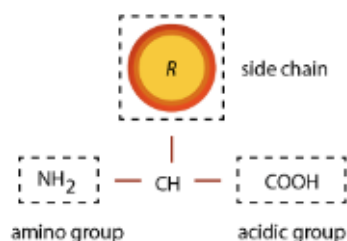


Figure 3.21 Fish meat contains proteins.

There are 20 different naturally occurring amino acids, for example, methionine and valine. They differ because of their different R groups. Amino acids are combined in various ways to form millions of different protein molecules, just as the 26 letters of the alphabet can be used to form a very large number of words.



Disciplinary Idea

Structure

Proteins are composed of multiple molecules of amino acids arranged in different ways.



Link

Chemistry

We learn that a polymer is a type of macromolecule formed by many small units called monomers linked together.



Helpful Note

Children who do not get enough protein may suffer from a protein deficiency disease called kwashiorkor. Such children usually have a pot-belly appearance with scaly, cracked skin.

Long Chains of Amino Acids Fold to Give Proteins a Three-dimensional Shape

Many amino acid molecules are joined in a linear manner to form a polypeptide. Polypeptides in turn may be linked up to form an even longer chain of amino acids. A protein molecule is made up of one or more such chains folded together (Figure 3.22). In most proteins, the polypeptide chains are folded into a more complex, three-dimensional shape.

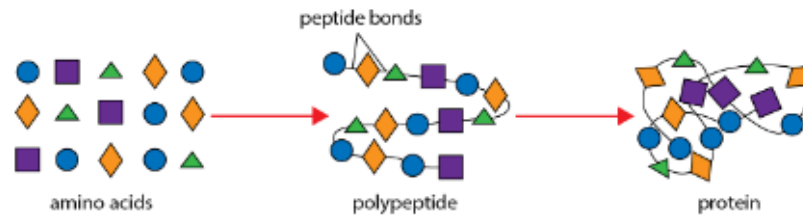


Figure 3.22 Amino acids are joined to form polypeptides, which link up to form even longer chains of amino acids.

What Are the Sources of Proteins?

Proteins can be found in both animal and plant foods. Milk, eggs, seafood and meat, such as chicken and lean beef, are some animal foods rich in proteins (Figure 3.23). Plant foods rich in proteins include soya beans, nuts, grains and vegetables such as French beans.

What Are the Functions of Proteins?

Proteins are used in the:

- synthesis of new cytoplasm, for growth and repair of worn-out body cells;
- synthesis of enzymes and some hormones; and
- formation of *antibodies* to combat diseases.

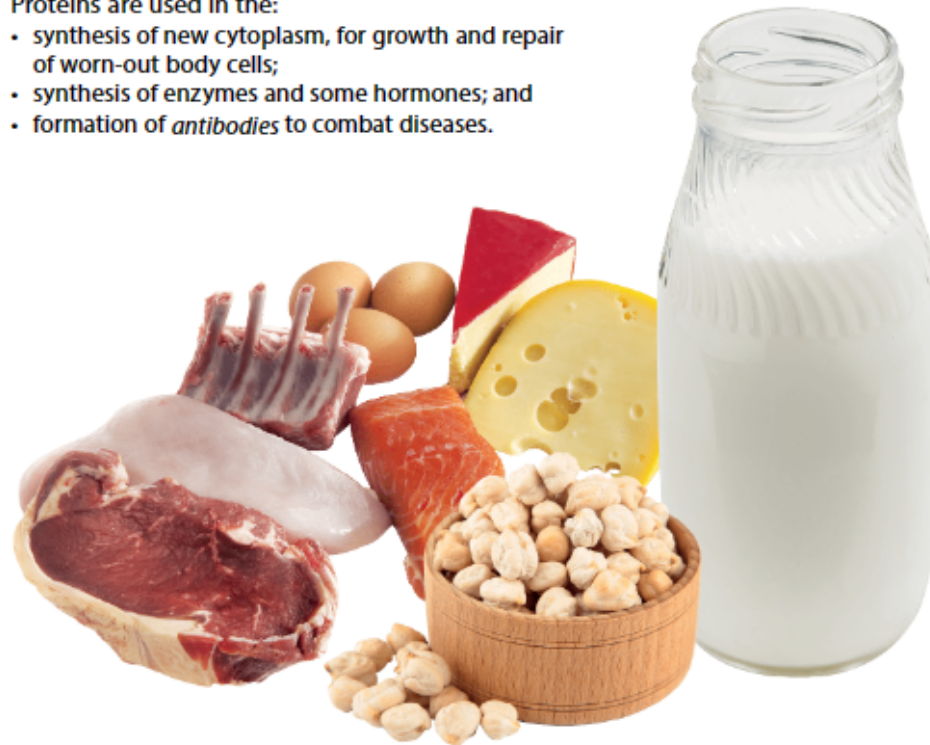


Figure 3.23 Examples of plant and animal proteins



How Can We Test for Proteins?

Proteins can be detected by the biuret test. The *biuret solution* is a blue solution made up of sodium hydroxide and copper(II) sulfate. It turns violet (deep purple) when proteins are present.

Let's Investigate 3.4

Aim

To test for the presence of proteins in a food sample (e.g. egg white) using biuret solution

Procedure

- 1 To 2 cm³ of liquid food sample (e.g. egg white), add an equal volume of biuret solution.
- 2 Shake well and allow the mixture to stand for five minutes.
- 3 Record your observation.



Figure 3.24 A violet (deep purple) colour indicates the presence of proteins. In the absence of proteins, the solution will remain blue.

Observation

A violet colour indicates the presence of proteins (Figure 3.24).

Question

What colour changes do you observe when the egg white is mixed with biuret solution?



Link

Practical Workbook
Experiment 3A

Let's Practise 3.3

- 1 (a) List the chemical elements that make up proteins.
(b) List **three** functions of proteins.
- 2 Describe how you would test for proteins in a food sample.
- 3 Food tests were carried out on three different foods, labelled A, B and C. The results of the tests are given in Table 3.4.

Table 3.4 Results of food tests

Test	A	B	C
Add iodine solution	Iodine remains brown	Iodine remains brown	Blue-black colour observed
Heat with Benedict's solution	Red precipitate formed	Red precipitate formed	Solution remains blue
Add biuret solution	Solution remains blue	Violet colour observed	Violet colour observed

- (a) Using the results from the table, state what substances are present in each food.
- (b) Describe how you would test for fats in a piece of skin from an orange.
- (c) Outline the role of proteins in the life of an organism.



Link

Theory Workbook
Worksheets 3A–3B
Let's Assess
Let's Reflect



Biology Connect

Scan the QR code to explore a simulation on testing for nutrients.



Link

Practical Workbook
Experiment 3B

How Can We Identify the Different Nutrients Present in Our Food?

You can carry out food tests on a variety of foods, for example, peanut, cucumber, onion, tomato and banana in order to find out what nutrients they contain. The following points in Let's Investigate 3.5 are worth noting.

Let's Investigate 3.5

- 1 To test a food for presence of reducing sugars or proteins, cut the food into small pieces or grind up the food with a pestle and mortar (Figure 3.25). This helps to break the cells and release the food substances so as to make a concentrated solution for testing.
 - (a) Place some crushed pieces of food in a test-tube. Add 2 cm³ of water to the test-tube to dissolve the sugars and proteins in the food.
 - (b) Decant the solution into another test-tube.
 - (c) Perform Benedict's or biuret test with the solution. (Refer to Let's Investigate 3.1 and 3.4 respectively.)
- 2 To test for starch, use the iodine test in Let's Investigate 3.2.
- 3 To test for fats, use the ethanol emulsion test in Let's Investigate 3.3.



Figure 3.25



Cool Career

Nutrition Coach

Nutrition coaches work with their clients to guide them towards a healthy lifestyle (Figure 3.26). They help their clients to incorporate healthy eating behaviours into their lifestyle.

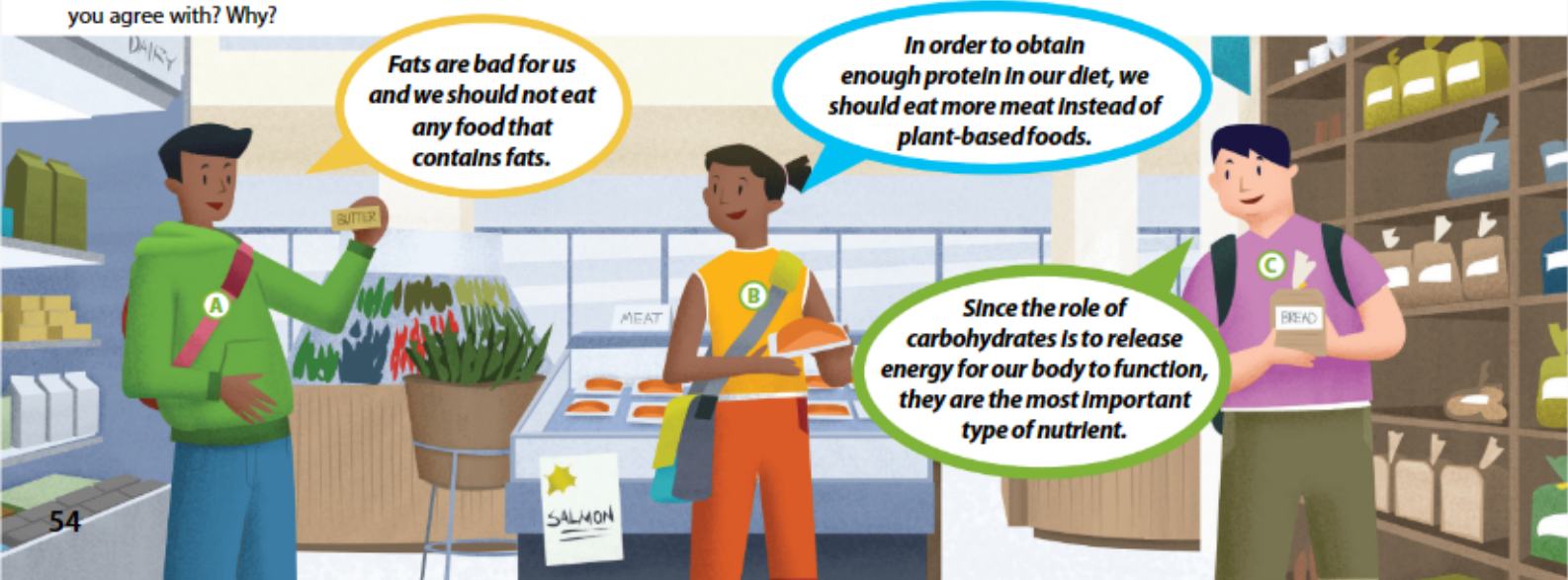
To be successful at this, nutrition coaches need to have a good knowledge of what nutrients can do for our health. They must have a good understanding of human behaviour, especially when people are faced with changes in life. They can incorporate healthy diets into the programmes to build the physical fitness of their clients.



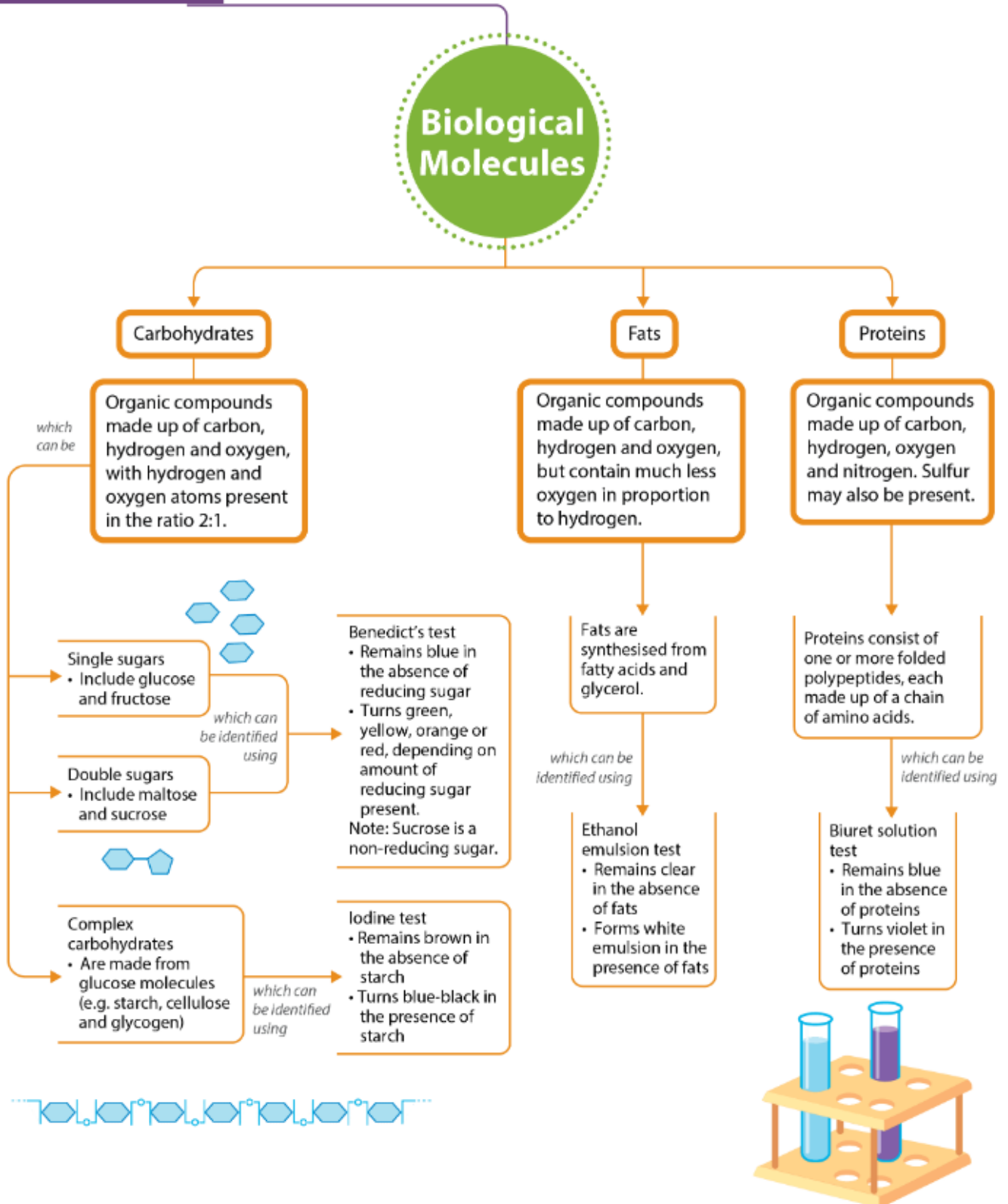
Figure 3.26 Nutrition coach and a patient discussing a diet plan

Figure 3.27 Three friends are having a discussion about nutrients. Who do you agree with? Why?

Now, look at Figure 3.27. Do you agree with what is said here? Why or why not?



Let's Map It



Let's Review

Section A: Multiple-choice Questions

- 1 Benedict's test was carried out on four solutions. The colour of the reaction at the end of the test is shown in Table 3.5.

Table 3.5

Solution	Colour
1	Turns green
2	Remains blue
3	Turns brick-red
4	Turns yellow

What is the best interpretation of the results?

	Solution 1	Solution 2	Solution 3	Solution 4
☒ A	0.05% glucose	0.5% starch	1.5% glucose	0.1% glucose
☐ B	1.0% glucose	1.0% starch	1.5% glucose	0.5% glucose
☐ C	0.5% starch	0.05% glucose	0.1% glucose	1.5% glucose
☐ D	1.0% starch	0.5% glucose	0.5% starch	0.1% starch

- 2 Which of the four substances listed below will give a violet colour when tested with biuret solution?

- ☒ A butter ☐ B cellulose
☐ C lean meat ☐ D glycogen

- 3 Which nutrient in a person's diet is used to make new enzyme molecules in his body?

- ☒ A carbohydrate ☐ B fat
☐ C protein ☐ D water

Section B: Structured Questions

- 1 Soldiers in the Arctic, who experience sub-zero temperatures, are recommended a diet rich in a certain nutrient. Such a diet is different from typical diets in tropical regions.
- (a) Which nutrient is the Arctic diet rich in?
- (b) Give a reason for your answer in (a).
- 2 (a) State the names of the chemical elements that make up carbohydrates and proteins.
- (b) State the basic molecules that are used to make these substances.
- (i) starch
(ii) glycogen
(iii) proteins
(iv) fats
- (c) State the importance of the following in our diet.
- (i) carbohydrates
(ii) fats
(iii) proteins

Section C: Free-response Question

- 1 Players are advised to eat bananas during long matches in a competition. Why?

CHAPTER

04 Enzymes



What You Will Learn



- What are enzymes?
- What are the characteristics of enzymes?

Isn't it amazing how the toughest stains can be removed from your favourite T-shirts after washing? It is not done with the aid of special powers. It is through "special powders". A lot of washing powders available in the market contain biological catalysts called enzymes. What are enzymes?



4.1 What Are Enzymes?

Learning Outcome

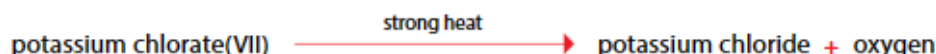
- Describe enzymes as biological catalysts, which are made of proteins and are involved in all metabolic reactions.

Biological Catalysts

Biological catalysts are large biological molecules called enzymes. Most enzymes are found in living organisms.

- A **catalyst** is a substance that can speed up a chemical reaction, without itself being chemically changed at the end of the reaction.

For example, potassium chlorate(VII) naturally breaks down (decomposes) to water and oxygen. This reaction occurs very slowly and at a high temperature.



When potassium chlorate(VII) is heated strongly in a test-tube, oxygen is given off. Gentle heating only melts the potassium chlorate(VII), and no oxygen is produced. If a little manganese(IV) oxide is added to the melted substance, the reaction is speeded up and oxygen is rapidly given off. Manganese(IV) oxide:

- allows the reaction to be carried out at a lower temperature; and
- speeds up the reaction.

At the end of the reaction, the same mass of manganese(IV) oxide remains, showing that it has not been changed in the reaction. Manganese(IV) oxide is an inorganic catalyst (Figure 4.1). Inorganic catalysts are not destroyed by boiling or by changes in the pH of the solution.

In the same way, complex apparatus and high temperatures are required to break down carbohydrates, fats or proteins in the laboratory. However, cells can carry out these same reactions quite rapidly without having to raise the body temperature. Cells carry out these reactions using catalysts called *enzymes*.

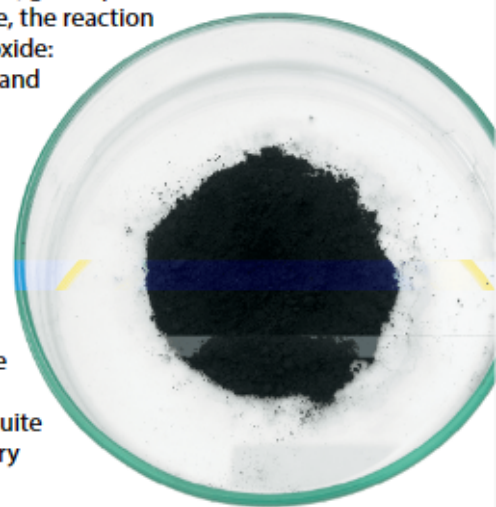


Figure 4.1 Manganese(IV) oxide is an inorganic catalyst.

Enzymes Are Biological Catalysts

- Enzymes** are proteins that function as biological catalysts. They catalyse or speed up the rate of chemical reactions. They remain chemically unchanged at the end of the reaction.

Enzymes are made up of protein molecules that are folded to take on three-dimensional globular shapes.



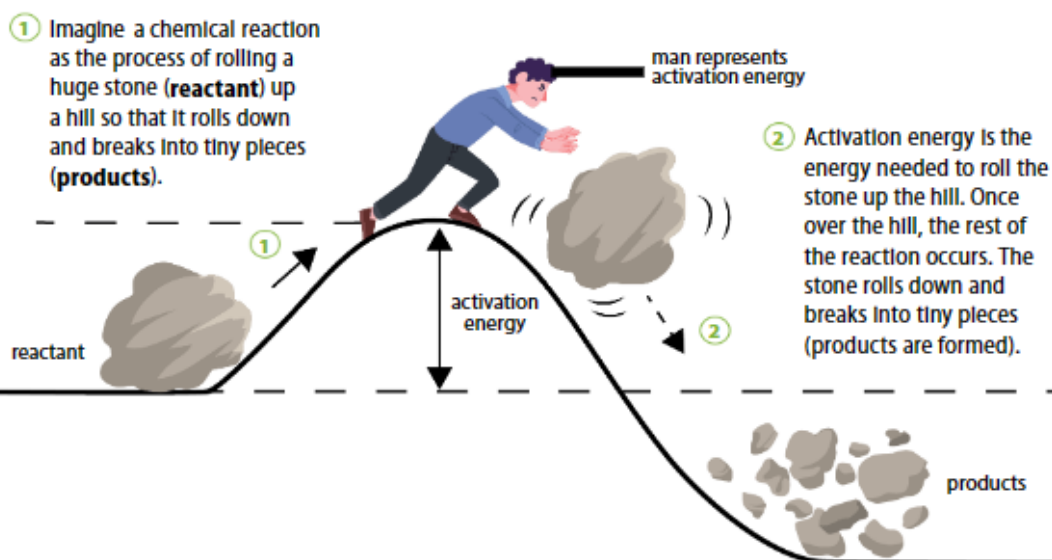
Link

What are proteins? Recall what you have learnt in Chapter 3.

Enzymes Lower Activation Energy

Fat in a peanut seed can be broken down by oxidation into carbon dioxide and water. This reaction can take place when the peanut is burnt. In other words, energy in the form of heat must be supplied to start breaking down the fat in the peanut seed.

The energy needed to start a chemical reaction is called **activation energy** (Figure 4.2).



Disciplinary Idea

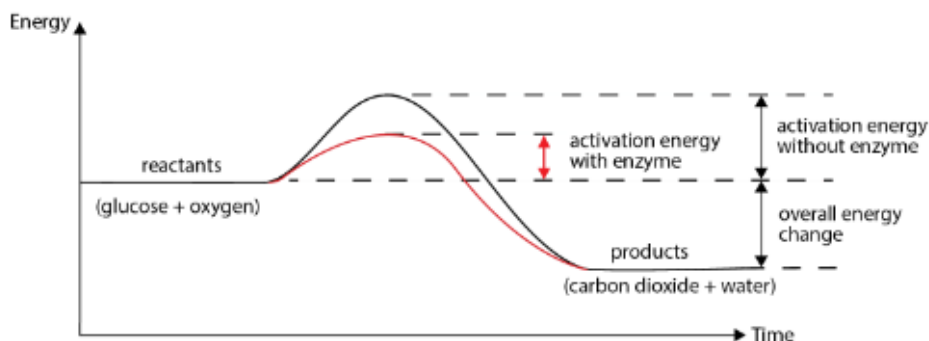
Energy

Enzymes help to lower the activation energy required to break down large molecules into smaller molecules.

Figure 4.2 Activation energy is needed to start a chemical reaction.

Enzymes provide an alternative pathway with lower activation energy required to start a chemical reaction. They lower the 'height' of the 'hill'. This is shown in the graph in Figure 4.3. Enzymes catalyse chemical reactions. They speed up the rate of chemical reactions by lowering the activation energy.

For example, enzymes speed up the breakdown of glucose to carbon dioxide and water (Figure 4.3) at body temperature (37 °C).



Note: If the overall energy change is negative, there is a decrease in energy content (as shown in graph). If the overall energy change is positive, there is an increase in energy content.

Figure 4.3 Activation energy for an enzyme-catalysed reaction



Link

Chemistry

We learn the effects of catalysts on the rate of reactions. Catalysts provide pathways with lower activation energies that increase rate of reactions. Enzymes are biological catalysts.

What Reactions Do Enzymes Catalyse?

Some food molecules are large and insoluble in water. These molecules cannot diffuse through the cell membrane.

Enzymes are required to break these large molecules into simpler and smaller substances so that they are:

- soluble in water
- small enough to diffuse through the cell membrane (Figure 4.4)



Link

What is digestion?
Read more about it in
Chapter 5.

Enzymes that are involved in digestion are known as **digestive enzymes**.

Examples of digestive enzymes are:

- amylase — digests starch to maltose
- maltase — digests maltose to glucose
- protease — digests proteins to polypeptides, then to amino acids
- lipase — digests fats to fatty acids and glycerol

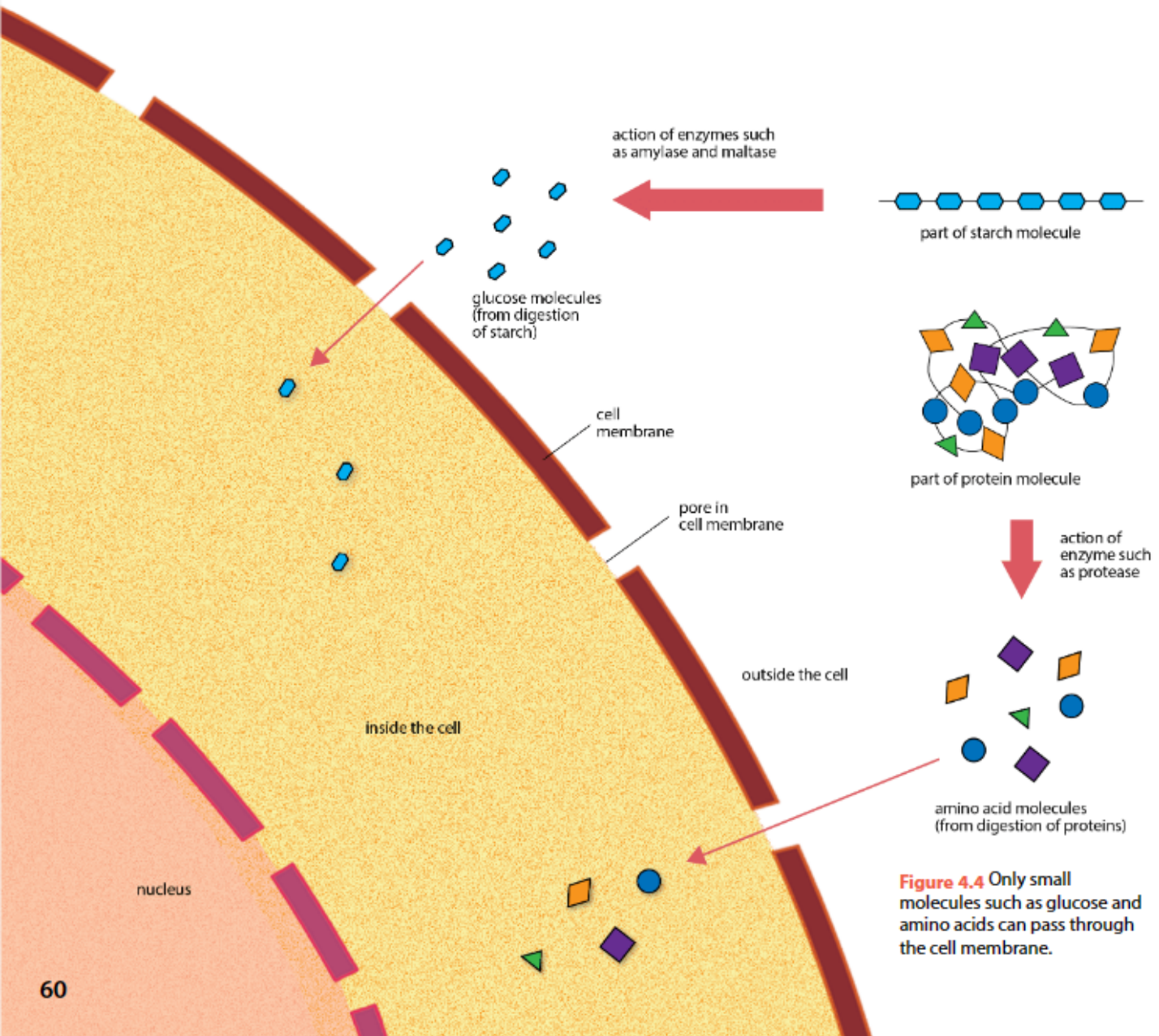


Figure 4.4 Only small molecules such as glucose and amino acids can pass through the cell membrane.

Enzymes Either Build Up or Break Down Complex Substances

Enzymes are also involved in biological reactions. Enzyme-catalysed reactions can be classified into:

- reactions that build up complex substances (anabolic reactions)
- reactions that break down complex substances (catabolic reactions)

Figure 4.5 shows examples of processes in which enzymes are involved.

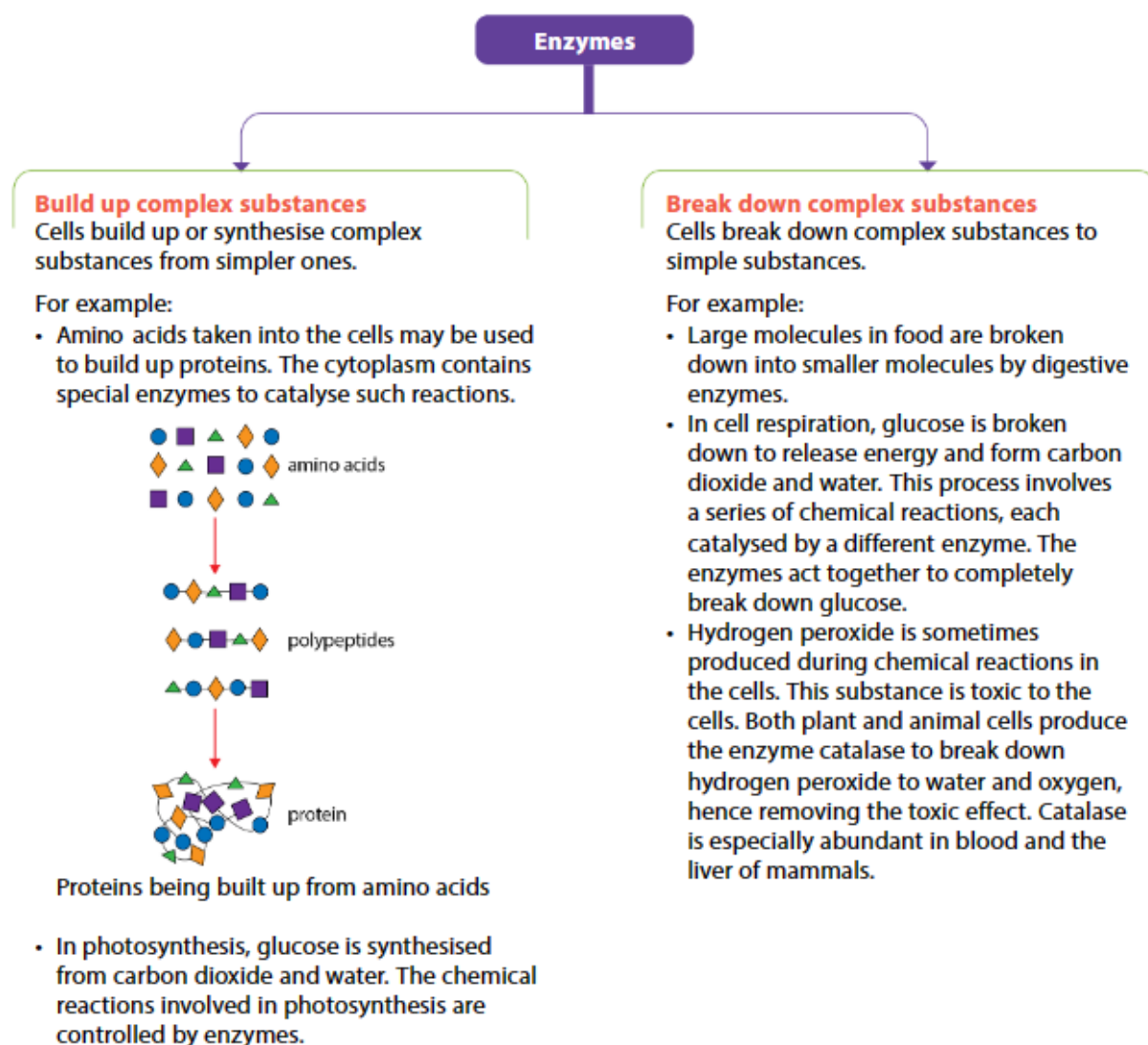


Figure 4.5 Two types of enzyme-catalysed reactions

From the above functions of enzymes, it is important to note that *enzymes catalyse practically all the chemical reactions that occur in an organism*. However, enzymes are produced only when they are needed. For example, digestive enzymes are produced only when there is food to digest in the alimentary canal.

How Are Enzymes Named?

Previously, enzymes were simply named by the persons who discovered them. For example, pepsin (a type of protease) was discovered and named by a scientist, Theodor Schwann (Figure 4.6), who was studying digestive processes. 'Pepsin' means 'to digest' in Greek.

However, naming enzymes this way led to a lot of confusion. Nowadays, enzymes are named according to a scientific system. The name of each enzyme:

- shows the substance on which the enzyme acts
- ends in 'ase'

For example, lipase refers to an enzyme that acts on lipids.

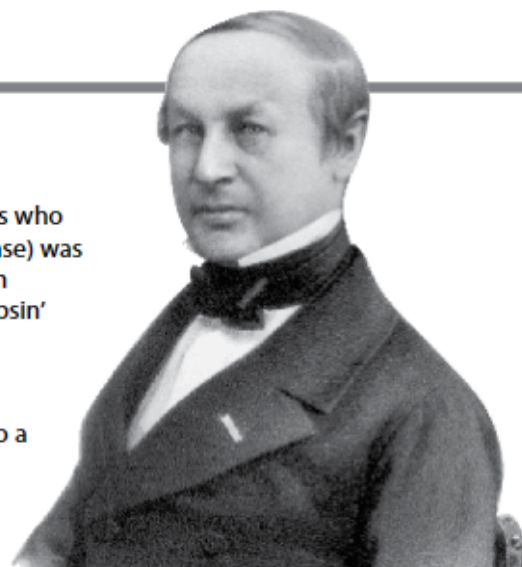


Figure 4.6 Theodor Schwann, German physician and physiologist

How Are Enzymes Classified?

Enzymes are classified according to the chemical reactions they catalyse. For example:

- **carbohydrases** are enzymes that digest carbohydrates
- **proteases** are enzymes that digest proteins
- **lipases** are enzymes that digest fats (lipids)

Let's Practise 4.1

- What is an enzyme?
 - What are the **two** types of reactions that enzymes catalyse?
- The unripe fruit of the papaya tree contains a particular type of digestive enzyme that is often used to soften meat.
 - Infer the kind of organic molecule that this enzyme acts on.
 - Suggest how the enzyme may cause the effect of softening of meat.
- Red blood cells contain a common enzyme known as catalase. What do you think would happen if a drop of blood was added to a solution of hydrogen peroxide?



Link

Theory Workbook
Worksheet 4A

4.2 What Are the Characteristics of Enzymes?

Learning Outcomes

- Explain the mode of action of enzymes in terms of an active site, enzyme–substrate complex, lowering of activation energy and enzyme specificity using the 'lock-and-key' hypothesis.
- Investigate and explain the effects of temperature and pH on the rate of enzyme-catalysed reactions.

Washing clothes in hot water is a traditional way of getting them very clean as the hot water helps in removing grease and dirt from soiled clothes. However, if you are using a biological washing detergent (Figure 4.7), which contains enzymes, it is recommended that you use lukewarm water instead of hot water. Why is this so? It is related to the nature of enzymes and how they function.



Figure 4.7 Enzyme-based biological detergent

How Does an Enzyme Work?

Enzymes are highly specific in their action. For example, amylases only act on starch, and not on proteins or fats. Similarly, proteases act only on proteins, and lipases only on fats. This **enzyme specificity** means that each chemical reaction inside a cell is catalysed by a unique enzyme.

An enzyme is specific in its action due to its three-dimensional shape. The 'lock-and-key' hypothesis explains how the shape of an enzyme affects the way it functions.

'Lock-and-key' Hypothesis

The substances on which enzymes act are called **substrates**. For example, protein is the substrate on which a protease acts.

According to the 'lock-and-key' hypothesis, enzyme reactions depend on the presence of **active sites** (Figure 4.8). Active sites are grooves (depressions) or 'pockets' on the surface of an enzyme molecule into which the substrate molecule(s) with the matching shape can fit — just like a lock and key. The enzyme is the lock, and the substrate is the key.



Disciplinary Idea

Structure and Function

The structure of biological molecules affects their functions. For example, the structure of enzymes affects the substrates that can fit into the active site. This affects the reactions they catalyse.

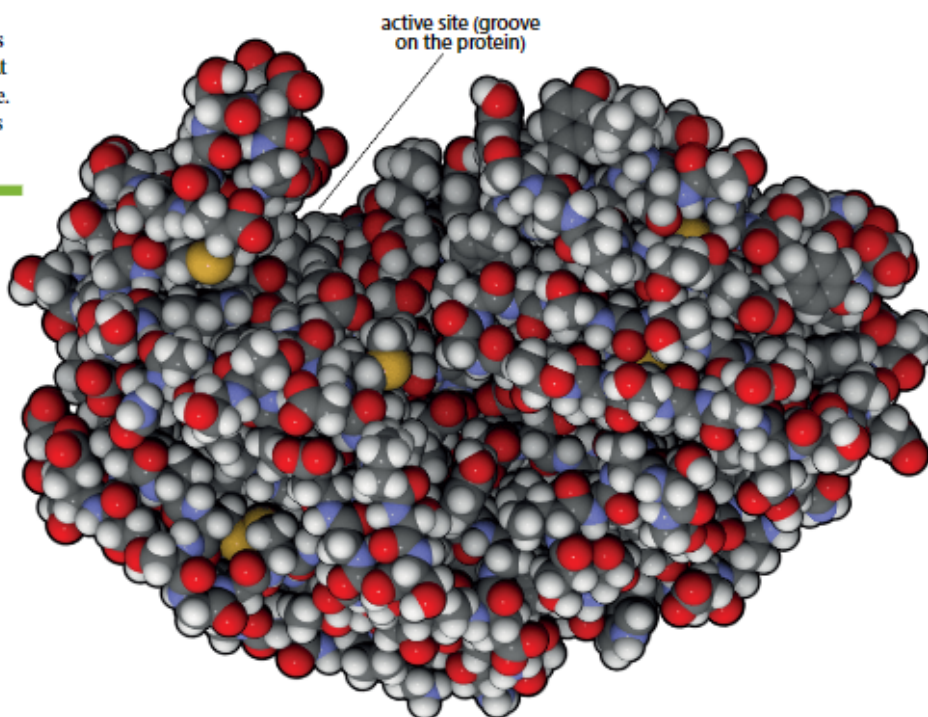


Figure 4.8 Three-dimensional model of enzyme pepsin with its active site

When the substrate binds to the active site of the enzyme, an **enzyme-substrate complex** is formed. It is a temporary molecule formed when substrates bind to the enzyme. Reactions take place at the active site to convert the substrate molecule(s) into product molecule(s). The product molecule(s) separate(s) from the enzyme. The enzyme molecule remains unchanged and is free to combine again with more substrate molecules.

The general equation is: $E + S \rightleftharpoons ES \rightleftharpoons E + P$

where **E** = enzyme
S = substrate(s)
P = product(s).

The specific nature of an enzyme for its substrate is described in Figure 4.9.

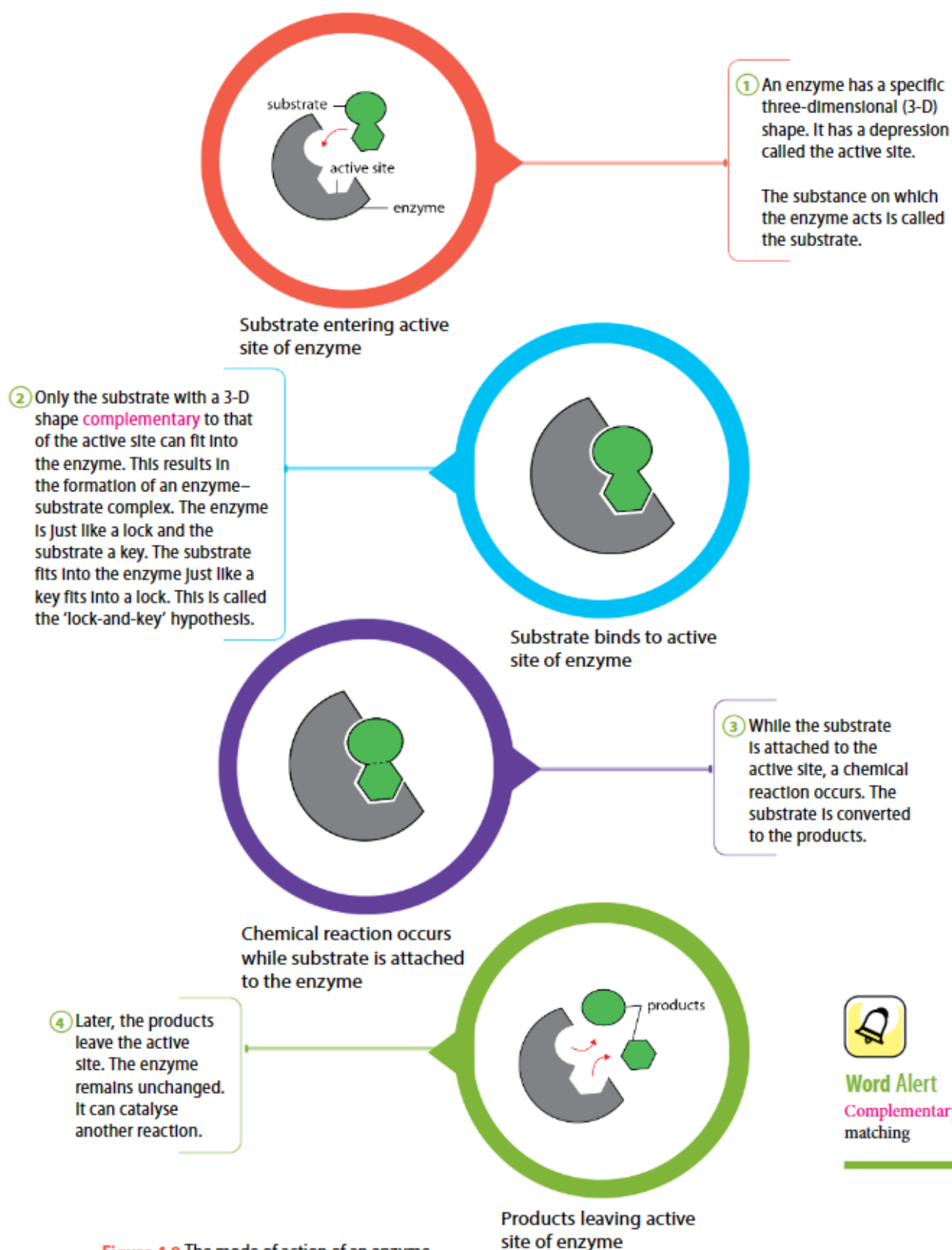


Figure 4.9 The mode of action of an enzyme



Characteristics of Enzymes

Enzymes Speed Up Chemical Reactions

Enzymes alter the rates of chemical reactions that occur in a cell. Enzymes speed up a chemical reaction by lowering the activation energy needed to start the reaction.

Enzymes Are Specific in Action

Enzymes have active sites. Only substrates with a shape complementary to the active site can fit into the enzymes. When an enzyme binds to its substrate, it forms an enzyme–substrate complex. However, high temperature, acids and alkalis can affect the shape of an enzyme and consequently its function.

Enzymes Are Required in Minute Amounts and Remain Unchanged at the End of Reactions

Enzymes are very efficient molecules. Since they remain unchanged in the reactions they catalyse, the same enzyme molecules can be used over and over again. Thus, a small amount of an enzyme can catalyse the reaction for a large amount of substrate. For example, just a spoonful of washing powder containing enzymes is enough to wash a large load of clothing.

Enzymes Are Affected by Temperature

Figure 4.10 shows the effect of temperature on the rate of enzyme reaction.

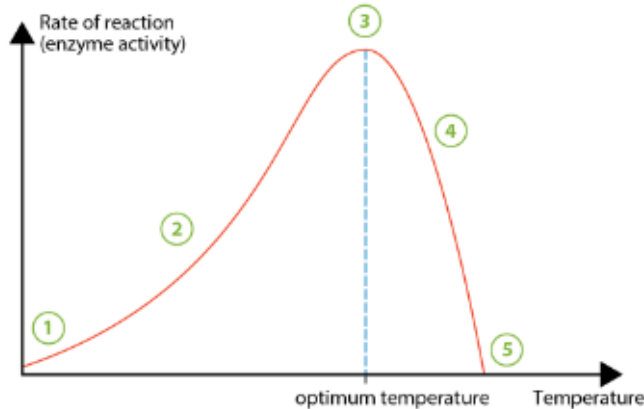


Figure 4.10 Effect of temperature on the rate of enzyme reaction

- ① **An enzyme is less active at low temperatures.**
At low temperature, the kinetic energy of molecules is low. Enzyme and substrate molecules move slowly. The rate of the substrate molecules colliding with the enzyme is very low.
- ② **As the temperature increases, the rate of enzyme reaction increases.**
Increasing the temperature increases the kinetic energy of molecules. The rate of effective collision (i.e. the rate of substrate molecules colliding and fitting into the active site of the enzyme) is increased. This increases the rate of enzyme–substrate complex formation.
- ③ **This is the optimum temperature, where the enzyme is most active.**
For most human enzymes, the optimum temperature is about 40–45 °C.



Word Alert

Optimum: most favourable

- ④ **Increasing the temperature above the optimum causes a rapid decrease in the rate of enzyme reaction.**
The active site of the enzyme molecule begins to lose its original shape and is no longer complementary to the shape of substrate molecules.
- ⑤ **At this temperature all the enzyme molecules have been denatured.**
Most enzymes are denatured.

► **Denaturation** is the change in the three-dimensional structure of an enzyme or any other soluble protein, caused by heat or chemicals such as acids or alkalis.

Denaturation results in the loss or alteration of the enzyme's active site (Figure 4.11). The substrate can no longer fit into the enzyme's active site, and no reaction will occur. Hence, when an enzyme is denatured, it can no longer act as a catalyst.

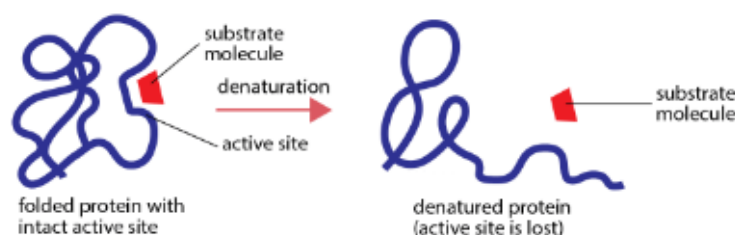


Figure 4.11 At temperatures above optimum, some enzymes are denatured. Enzymes lose their active sites when they are denatured.

Let's Investigate 4.1

Aim

To find out how temperature affects enzyme action

Procedure

- 1 Label and fill test-tubes A₁, B₁, C₁ and D₁ with 5 cm³ of starch solution respectively.
- 2 Label and fill test-tube D₂ with 3 cm³ of distilled water, and test-tubes A₂, B₂ and C₂ with 3 cm³ of amylase solution respectively.
- 3 Set up the experiment (see Figure 4.12 on the next page) by placing the test-tubes into water-baths of varying temperatures as shown in the table below.

Test-tubes	A ₁ , A ₂	B ₁ , B ₂	C ₁ , C ₂	D ₁ , D ₂
Temperature / °C	0	37	100	37

- 4 After 5 minutes, pour the contents of test-tubes A₂, B₂, C₂ and D₂ into test-tubes A₁, B₁, C₁ and D₁, respectively. Shake to mix the contents in each test-tube. Return the test-tubes to their respective water baths.
- 5 After 1 minute, remove one drop from each solution with a dropping pipette and put it in the well in the plate provided. Then test it with a drop of iodine solution. (The solution turns blue-black if starch is present.)
- 6 Continue step 5 at 1-minute intervals until the iodine solution remains brown. This shows that all the starch has been digested.
- 7 Record the total time (T) taken (in minutes) for the starch in each test-tube to be completely digested.



Link

Practical Workbook
Experiments 4A–4B



Helpful Note

Optimum pH values of some enzymes:

- amylase (a carbohydrase) in saliva: pH 7
- protease in stomach: pH 2
- protease in small intestine: pH 8



Disciplinary Idea

Structure and Function

Enzymes are proteins, and hence are affected by all the conditions that affect proteins, such as temperature and pH. They have optimal ranges of temperature and pH.



Biology Connect

Scan the QR code to explore a simulation on the effects of temperature and pH on the rate of enzyme reaction.

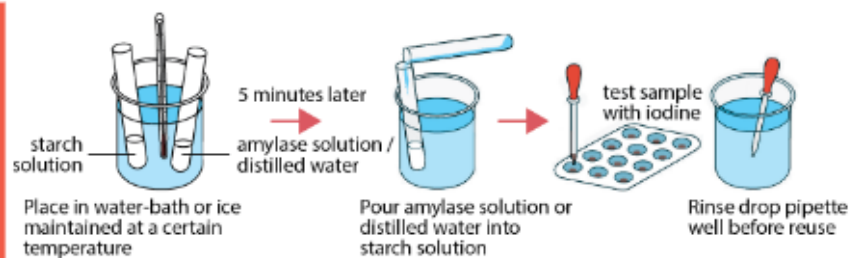


Figure 4.12 Experimental set-up to show how temperature affects enzyme action

Observation

- 1 The iodine solution turned blue-black when test-tube A₁ was tested for starch at the various 1-minute intervals.
- 2 The iodine solution remained brown when test-tube B₁ was tested for starch after 7 minutes.
- 3 The iodine solution turned blue-black when test-tube C₁ was tested for starch at the various 1-minute intervals.
- 4 The iodine solution turned blue-black when test-tube D₁ was tested for starch at the various 1-minute intervals.

Conclusion

- 1 The less time taken to digest starch, the more active the enzyme is. In this investigation, enzyme activity is measured by calculating $\frac{1}{T}$ (the reciprocal of the time taken to digest starch). What can you conclude about the effect of temperature on the activity of amylase from the graph of $\frac{1}{T}$ against temperature?

Enzymes Are Affected by pH

Enzymes are affected by the acidity or alkalinity of the solutions in which they act. Some work best in acidic solutions (for example, protease in the stomach), others require alkaline solutions (for example, intestinal enzymes). When enzymes are placed in pH conditions that vary from the optimum, they start to denature. Extreme changes in the acidity or alkalinity of the solutions denature the enzymes.

In Figure 4.13, point M indicates maximum activity of amylase at a pH of about 7 (optimum pH). As the solution becomes acidic (from pH 7 to 5) or alkaline (from pH 7 to 9), its activity decreases. At pH 4 or above pH 9, the enzyme is completely denatured.

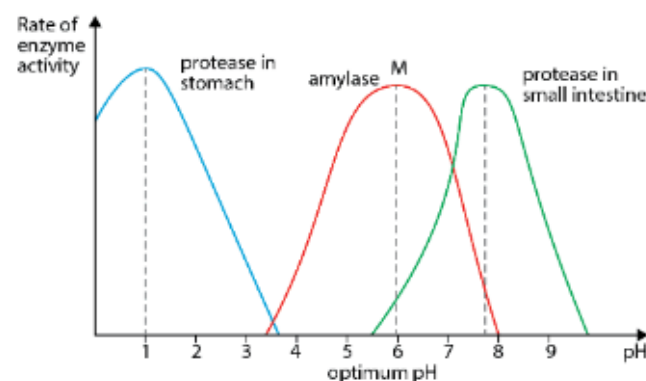


Figure 4.13 Effect of pH on the rate of reactions catalysed by different enzymes



Tech Connect

Some COVID-19 vaccines need to be stored at low temperatures for them to be effective. In some instances, the vaccines need to be stored at temperatures as low as -70°C .

At this very low temperature, enzymatic reactions that could break down the mRNA (a type of genetic material) in the vaccine are literally frozen to a halt. Scientists and engineers thus need to design, construct and use special freezers that have the ability to maintain such sub-arctic temperatures. They also need to design and construct containers that can store and transport large quantities of the vaccines across the world, from the place where it is manufactured to reach different countries.

These special freezers and containers are examples of technology in action. Engineers apply their knowledge in cooling systems to design and build machines that work to prevent enzymatic reactions on the vaccine ingredients during storage and transport (Figure 4.14).

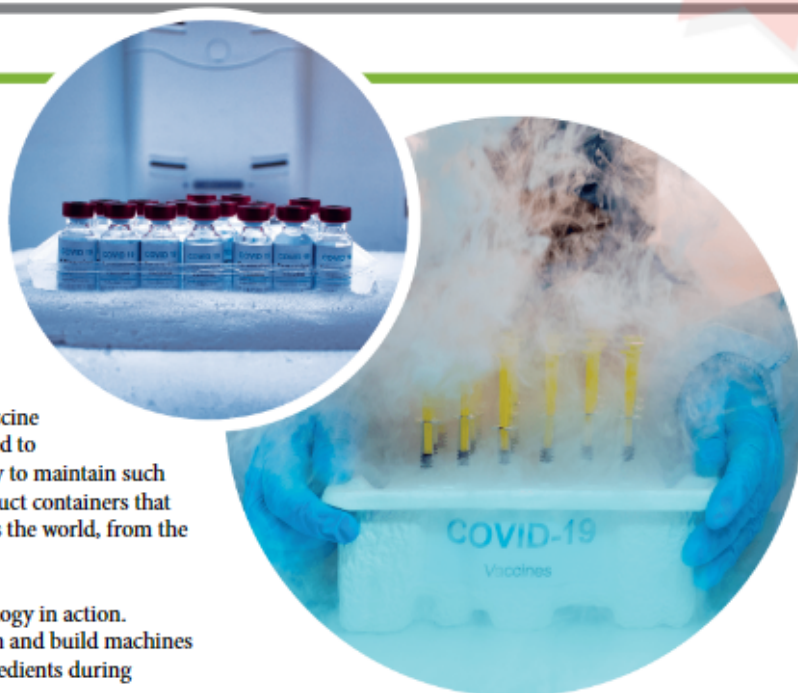


Figure 4.14 Storage of Covid-19 vaccine in freezers

You have learnt how enzymes break down large molecules in food into smaller molecules. Now look at Figure 4.15. What are your views on the statements made by the three people?



Figure 4.15 Three people are discussing the effect of enzymes on silk clothing. What is your view?

The experiment in Let's Investigate 4.2 is based on the fact that egg albumen (egg white) contains protein. Protease is a protein-digesting enzyme produced by the stomach. This experiment is designed to test how pH affects the activity of pepsin.

Let's Investigate 4.2

Aim

To investigate how pH affects enzyme action

Procedure

- 1 Label four test-tubes A, B, C and D, respectively.
- 2 Fill the four test-tubes as follows:

Table 4.1

Test-tube	Contents
A	a piece of boiled egg white + 10 drops dilute hydrochloric acid + 3 cm ³ protease found in the human stomach
B	a piece of boiled egg white + 10 drops dilute hydrochloric acid + 3 cm ³ distilled water
C	a piece of boiled egg white + 10 drops dilute sodium carbonate + 3 cm ³ protease found in the human stomach
D	a piece of boiled egg white + 10 drops distilled water + 3 cm ³ protease found in the human stomach

Observation and Discussion

- 1 Which test-tube is protease active in? What would be observed in this test-tube?
- 2 What are the purposes of test-tube B and test-tube D?



Link

Practical Workbook
Experiments 4C–4D



Link

Theory Workbook
Worksheet 4B
Let's Assess
Let's Reflect

Let's Practise 4.2

- 1 Figure 4.16 represents the action of an enzyme.
 - (a) Name **two** properties of enzymes that are illustrated in the figure.
 - (b) State **two** other features, not necessarily shown in the figure.

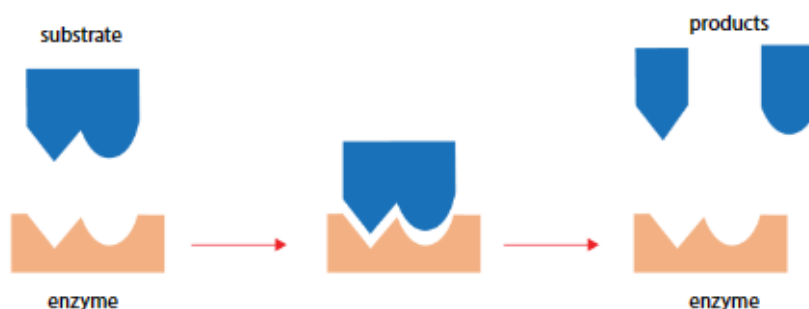


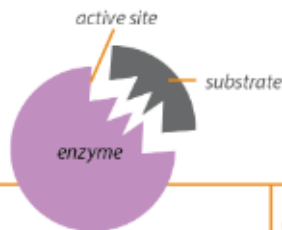
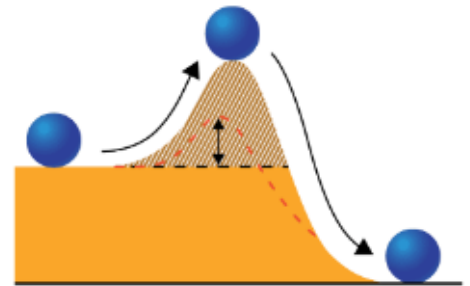
Figure 4.16

- 2 What is the process of denaturation in enzymes?

Let's Map It

Enzymes

are Biological catalysts



Functions

which include

- Digesting large food molecules into smaller molecules
- Breaking down food substances in cells to release energy (cellular respiration)
- Building up or synthesising complex substances
- Breaking down toxic substances in cells

Characteristics

which include

- Speeding up chemical reactions without being chemically changed
- Being required in small amounts
- Being highly specific
- Working best at an optimum temperature and pH
- Catalysing reversible reactions

Mode of action

which includes

- Providing an alternative pathway with lower activation energy required for a reaction
- Interacting with the substrate according to the 'lock-and-key' hypothesis to form an enzyme-substrate complex

Type of reaction catalysed

which includes

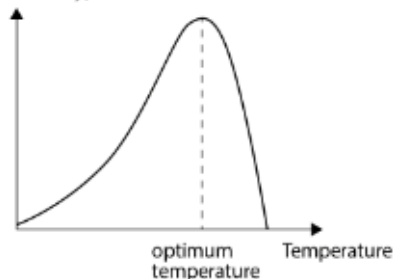
- Carbohydrases that digest carbohydrates
- Proteases that digest proteins
- Lipases that digest fats (lipids)

that can be affected by

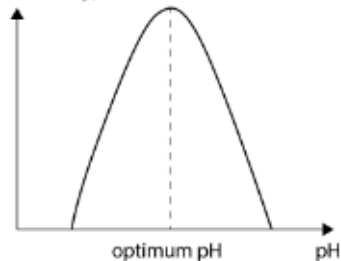
Changes in temperature or pH

- Increasing the temperature increases the rate of enzyme reaction until the optimum temperature is reached.
- Increasing or decreasing the pH from the optimum decreases enzyme activity.
- Enzyme denaturation takes place when there are extreme changes in pH and at a temperature above the optimum.

Rate of reaction (enzyme activity)



Rate of reaction (enzyme activity)



Let's Review

Section A: Multiple-choice Questions

- 1 A Petri dish was filled with agar jelly containing starch. Four holes were cut in the jelly. Each hole was filled with the substances shown in Figure 4.17.

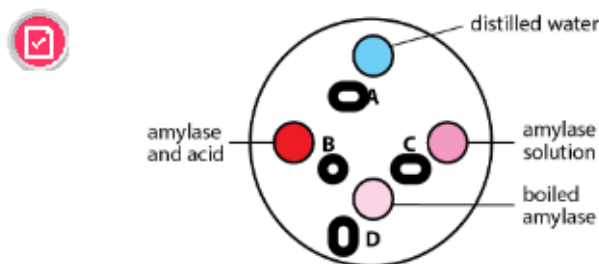
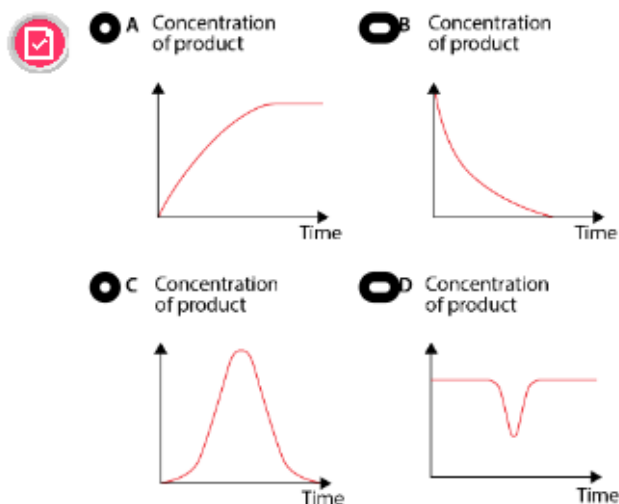


Figure 4.17

After 30 minutes, iodine solution was poured over the jelly. Which hole has the largest yellow-brown region surrounding it?

- 2 Which graph shows the changes in the concentration of the product in an enzyme-controlled reaction?



Section B: Structured Questions

- 1 Why are enzymes so specific in their actions?
- 2 State **three** characteristics of enzymes.

- 3 Digestive enzymes are used in some washing powders. The stains on your clothes caused by organic matter, such as sweat, blood, curry and plant material, consist of large molecules, often proteins and fats. These large molecules do not dissolve easily in water.

- (a) How would digestive enzymes help to clean clothes with proteins and fats on them?
- (b) It is recommended on the packet of biological washing powders that clothes be washed at low temperatures (less than 45 °C). Why?
- (c) To solve this problem, industrial biologists studied the enzymes of sulfur bacteria that flourish in hot springs. Here, the water temperature is often close to the boiling point. Why would using enzymes from these organisms make a better biological washing powder?



Section C: Free-response Questions

- 1 Describe how an enzyme works.
- 2 Explain the effect of temperature on the rate of an enzyme-controlled reaction.



Link

Theory Workbook
Revision Worksheet 1

CHAPTER

05 Nutrition in Humans

What You Will Learn



- What is nutrition?
- What is digestion?
- What is absorption?
- What happens to the absorbed nutrients?
- What are the effects of alcohol consumption?



The food packaging we find in supermarkets usually have nutritional labels that tell us the nutrients and the amount of those nutrients present in the food we are buying.

How does our body get the nutrients present in these food?

In this chapter, we will find out how nutrients are released from the food we eat and the processes involved. We will also take a look at organs that play an important role in digestion and assimilation of food.



5.1 What Is Nutrition?

Learning Outcomes

- Describe the functions of the various parts of the digestive system: mouth, salivary glands, oesophagus, stomach, duodenum, pancreas, gall bladder, liver, ileum, colon, rectum, anus, in relation to ingestion, digestion, absorption, assimilation and egestion of food, as appropriate.
- Describe peristalsis in terms of rhythmic wave-like contractions of the muscles to mix and propel the contents of the alimentary canal.

Why do parents tell their children not to talk with their mouths full? Is it bad manners? At times, it could be life threatening. You could choke if you eat and talk at the same time (Figure 5.1). How does food pass through your body the right way and get absorbed? To answer these questions, we need to find out more about nutrition and the digestive system.



Figure 5.1 Eating and talking at the same time may lead to choking.

► **Nutrition** is the process by which organisms obtain food and energy for growth, repair and maintenance of the body.

In humans, nutrition consists of the following processes:

- **Feeding or Ingestion** — Food is taken into the body.
- **Digestion** — Large food molecules are broken down into smaller, soluble molecules that can be absorbed into the body cells.
- **Absorption** — Nutrients move from the small intestine into the bloodstream.
- **Assimilation** — Nutrients are used by cells to provide energy or to make new cytoplasm for growth.
- **Egestion** — Undigested matter is removed from the body.

The Human Digestive System

The human digestive system consists of the gut or **alimentary canal** and the **organs (liver, gall bladder and pancreas) associated with it** (Figure 5.2). The alimentary canal is a nine-metre long tube that extends from the mouth to the anus, with most of its length coiled in the abdomen or abdominal cavity. The alimentary canal makes up a large part of the organ system for nutrition.

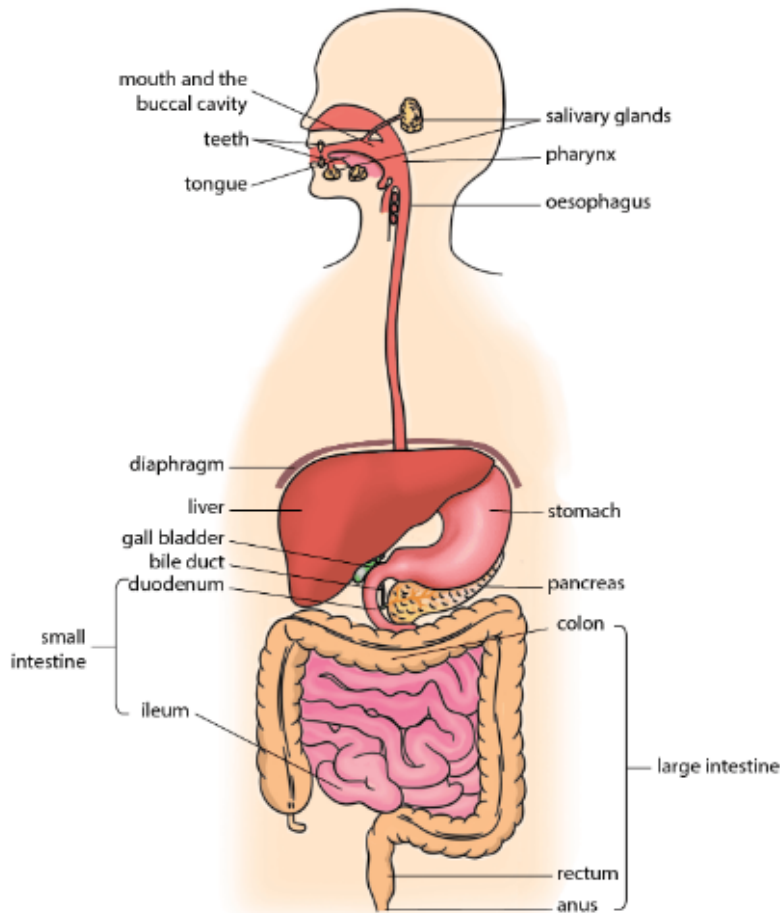


Figure 5.2 The human digestive system

The Mouth and the Buccal Cavity

Food enters the body through the mouth, which leads into the buccal cavity. The buccal cavity is the inside of the mouth and the beginning of the alimentary canal. In the mouth there are:

- Teeth that break large pieces of food into smaller pieces. This increases the surface area of the food so that enzymes can act on it more efficiently.
- Salivary glands that secrete saliva into the mouth.
- A tongue that mixes the food with saliva and moves the food to the back of the mouth during swallowing.



Disciplinary Idea

Systems

The digestive system consists of the alimentary canal and the associated organs that work collaboratively to break down large, insoluble molecules of food into smaller soluble molecules that can be absorbed and assimilated by the body.



Helpful Note

A gland is a cell, a tissue, or an organ that produces and secretes a chemical substance. For example, salivary glands secrete saliva. The liver and pancreas are also glands.



Helpful Note

The diaphragm is a sheet of muscle which separates the thorax (chest) from the abdomen. Below the diaphragm lies the stomach and the liver.

The Pharynx

The **pharynx** is the part of the alimentary canal that connects the buccal cavity to the oesophagus and the larynx (voice-box). The pharynx also leads to the trachea (windpipe).



Helpful Note

The larynx has a slit-like opening called the glottis (Figure 5.3). Both food and air pass through the pharynx when they enter the body. Normally, air passes through the trachea, while food passes through the oesophagus. People tend to choke when they talk while swallowing. As the epiglottis cannot fully close when one is talking, the food enters the trachea causing one to choke.

The Process of Swallowing

During swallowing, food could pass into the trachea instead of the oesophagus. A piece of flap-like tissue called the **epiglottis** usually prevents food from going down the wrong way. The epiglottis is above the larynx, just behind the root of the tongue. During swallowing, the larynx moves up and the epiglottis moves downwards so that the larynx is covered by the epiglottis. No food particles can enter the trachea. This prevents choking.

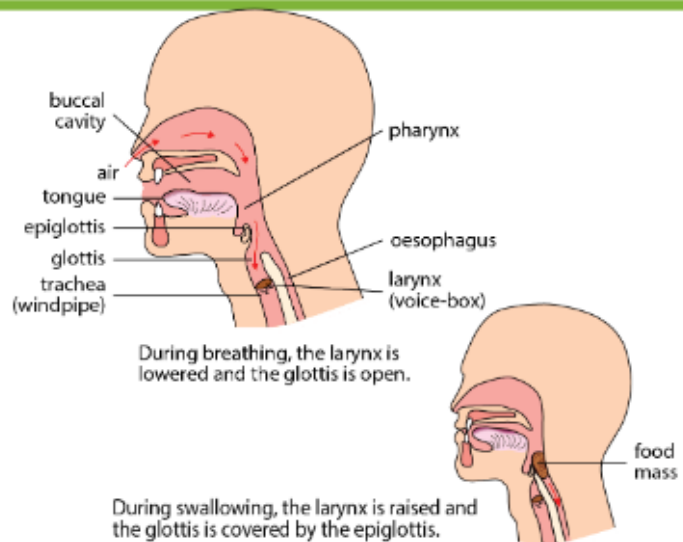


Figure 5.3 What happens during breathing and swallowing

Let's Investigate 5.1

- 1 Place your fingers against your larynx (voice-box).
- 2 Swallow your saliva. Write down the details of what happens to your throat.
- 3 Account for the movement in your throat.

The Oesophagus

The **oesophagus** or gullet is a narrow, muscular tube. It passes through the thorax (chest) and joins the mouth to the stomach (Figure 5.2).

The wall of the oesophagus contains two layers of muscles (Figure 5.4). These muscles are present along the whole gut from the oesophagus to the rectum.

The two layers of muscles are:

- the **longitudinal muscles** on the outer side of the gut wall and
- the **circular muscles** on the inner side of the gut wall.

Both sets of muscles produce long, slow contractions. These contractions move food along the gut via peristalsis.

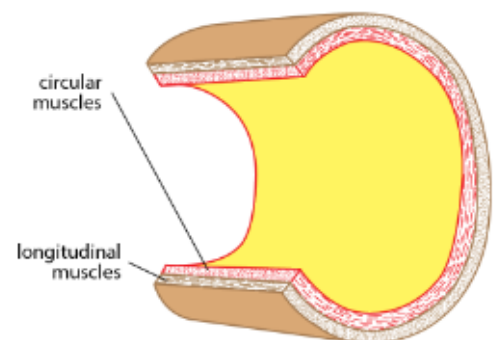


Figure 5.4 Part of the gut wall

Peristalsis

- **Peristalsis** is the rhythmic, wave-like muscular contractions in the wall of the alimentary canal.

Peristalsis enables food to be mixed with digestive juices, and also pushes or propels the food along the gut. Figure 5.5 shows how peristalsis occurs.

When the circular muscles contract, they constrict the lumen. When the longitudinal muscles contract, they shorten and widen the lumen. The circular muscles and longitudinal muscles are **antagonistic** muscles. This means that when one set of muscles contracts, the other set relaxes.

- When the circular muscles contract, the longitudinal muscles relax. As a result, the wall of the gut constricts, that is, the gut becomes narrower and longer. The food is squeezed or pushed forward.
- When the longitudinal muscles contract, the circular muscles relax. The gut dilates, that is, it becomes wider and shorter. This widens the lumen for the food to enter.

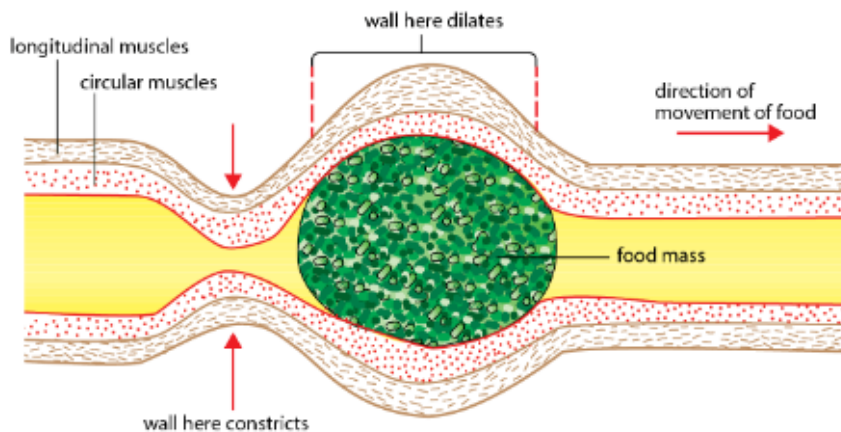
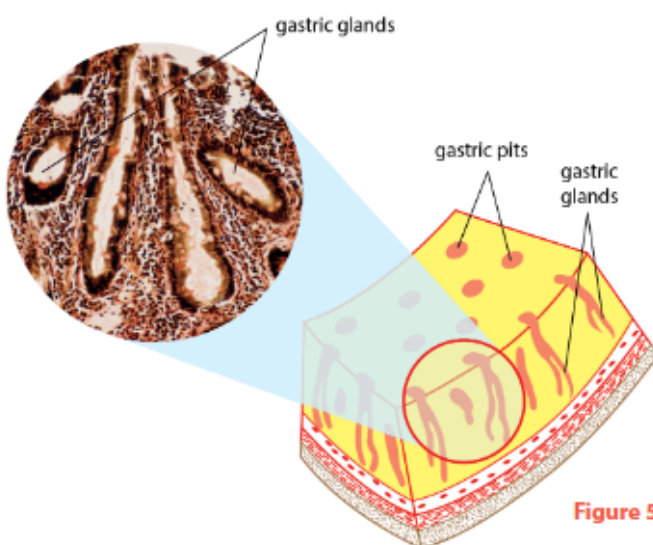


Figure 5.5 Action of the antagonistic muscles of the gut wall, resulting in peristalsis



Word Alert

Antagonistic: working in opposite directions



The Stomach

The stomach is a distensible muscular bag, with thick and well-developed muscular walls. It lies to the left side of the abdominal cavity and is partly covered by the liver. The inner surface of the stomach wall has numerous pits, the walls of which are lined with **gastric glands** (Figure 5.6). These glands secrete **gastric juice** which plays an important part in digestion.

Figure 5.6 Section of the stomach wall



Helpful Note

Where the stomach joins the small intestine, there is a muscular valve called the *pyloric sphincter*. When the muscles contract, the entrance to the small intestine closes. When the muscles relax, the entrance opens, allowing food to pass from the stomach into the small intestine.

The Small Intestine

The small intestine consists of a U-shaped **duodenum** (the first part of the small intestine) and the much-coiled **ileum**. In humans, the small intestine is about six metres long.

The small intestine carries out most of the digestive process. The lining of the walls of the small intestine contains glands that secrete digestive enzymes. With these enzymes and the enzymes from the pancreas, food is digested. The detailed structure of the wall of the small intestine is shown in Figure 5.18 on page 86. Water and nutrients from the food we eat are absorbed in the small intestine.

The Large Intestine

The large intestine is shorter but much broader than the small intestine. The small intestine opens into the large intestine in the right side of the abdominal cavity.

The large intestine is about 1.5 metres long and consists of the **colon**, **rectum** (a short muscular tube) and **anus**.

Faeces (undigested matter) are stored temporarily in the rectum. When the rectum contracts, the faeces are expelled through the anus. The main function of the colon is to absorb about 90% of the remaining water and mineral salts from the undigested food material.

Organs and Glands Associated with the Gut

The Liver and the Gall Bladder

The liver is the largest gland in the body. It is dark red in colour and its upper surface touches the diaphragm and the lower surface is in contact with the stomach and the small intestine. Attached to the lower surface of the liver are three blood vessels, the hepatic portal vein, the hepatic vein and the hepatic artery (Figure 5.7).

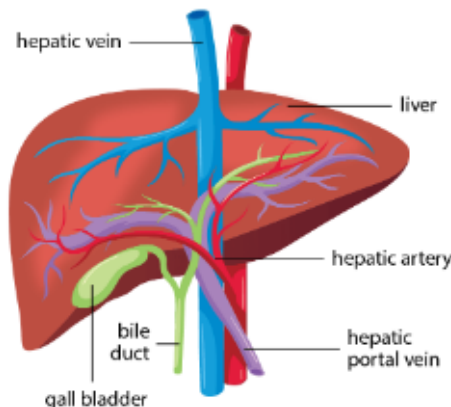


Figure 5.7 Liver and its blood vessels

Liver cells produce and secrete **bile**, an alkaline greenish-yellow liquid containing bile salts. It does not contain enzymes, so it cannot chemically digest food but it aids in the physical digestion of fats (see emulsification of fats on page 83).

Bile is stored temporarily in the gall bladder. The gall bladder is a greenish-yellow bag attached to the liver. When the gall bladder contracts, the bile flows into the duodenum via the **bile duct**.

The liver has many other important functions to perform apart from its role in digestion (see Section 5.4).

Figure 5.8 shows some organs and glands related to digestion.

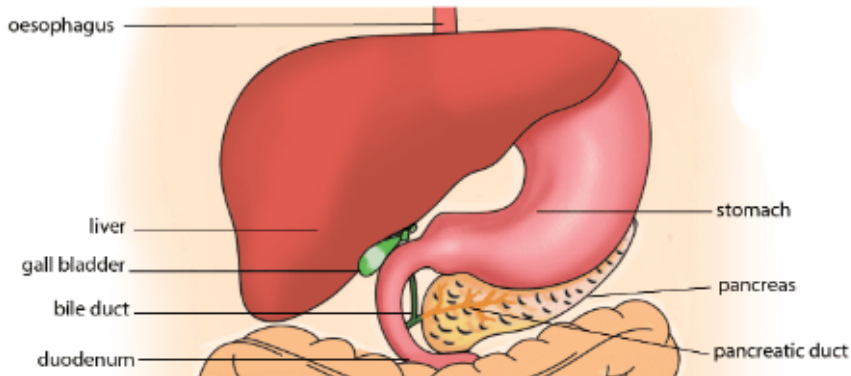


Figure 5.8 Position of liver and pancreas in relation to stomach and duodenum

The Pancreas

The pancreas is a gland lying in the loop of the duodenum. It is connected to the duodenum by the **pancreatic duct**. The bile duct joins the pancreatic duct just before the pancreatic duct opens into the duodenum.

The pancreas produces **pancreatic juice** which contains digestive enzymes, amylase, lipase and protease. The pancreas also secretes the hormones insulin and glucagon, which play an important role in the control of the blood sugar level in the body.

Let's Practise 5.1

Figure 5.9 shows peristalsis.

- 1 For contraction at A, which muscles contract and which relax to cause the wall here to constrict?
- 2 For dilation at B, which muscles contract and which relax to cause the wall here to dilate?
- 3 Draw an arrow to show the direction of movement of the food.

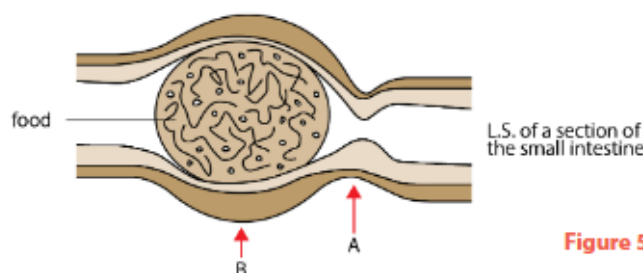


Figure 5.9



Link

Theory Workbook
Worksheet 5A

5.2 What Is Digestion?

Learning Outcome

- Describe the functions of enzymes (e.g. amylase, maltase, protease, lipase) in digestion, listing the substrates and end-products.

Sometimes people have organs removed because of illnesses such as cancer. If an organ involved in digestion is removed, the person may need to avoid certain foods. Why is this so? We need to consider how the organ is related to the digestion of the type of food.

Digestion in Humans

- **Digestion** is the process whereby large food molecules are broken down into smaller, soluble molecules that can be absorbed into the body cells.

Digestion involves two processes: **physical digestion** and **chemical digestion**.

Physical digestion involves the mechanical break-up of food into small particles. This occurs:

- in the mouth, when you chew food by the action of the teeth and tongue; and
- in the stomach, where continual contractions and relaxations of the muscles in the stomach wall cause a churning action. This breaks up the food particles and mixes them with digestive enzymes.
- in the small intestine, where fats are broken up into small fat molecules by bile salts (see Figure 5.15).

Physical digestion increases the surface area-to-volume ratio of the ingested food so that digestive enzymes can act on the food more efficiently.

Chemical digestion is the breaking down of the large molecules in food, such as proteins, starch and fats, into small soluble molecules that can be absorbed. Figure 5.10 shows how starch is digested into maltose by the enzyme amylase.



Link

How do enzymes catalyse reactions? Recall what you have learnt in Chapter 4.

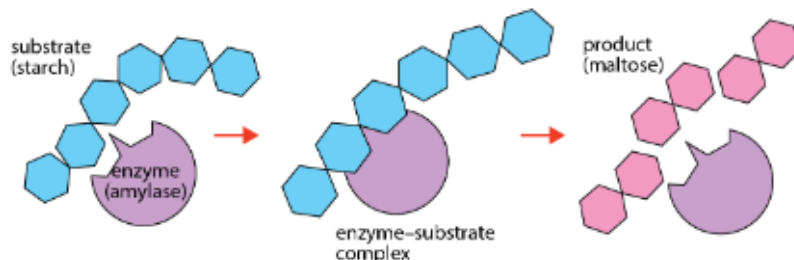


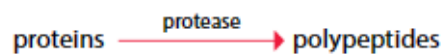
Figure 5.10 Chemical digestion of starch by amylase

Processes That Take Place in the Mouth

- 1 Food in the mouth stimulates the salivary glands to secrete saliva.
- 2 Saliva is mixed with the food to soften it.
- 3 Saliva contains an enzyme called salivary **amylase**, which digests starch to maltose.
- 4 The optimum pH for salivary amylase is at pH 7, at which the enzyme is most active.
- 5 Chewing breaks the food up into smaller pieces. This increases the surface area-to-volume ratio for salivary amylase to work on.
- 6 The tongue rolls the food into small, slippery, round masses or **boli** (singular: **bolus**).
- 7 The boli are swallowed and passed down into the oesophagus via the pharynx.
- 8 Peristalsis in the walls of the oesophagus pushes each bolus of food down into the stomach.

Processes That Take Place in the Stomach

- The presence of food in the stomach stimulates the gastric glands to secrete gastric juice into the stomach cavity.
- Peristalsis in the stomach wall churns and breaks up the food. Peristalsis also mixes the food well with gastric juice.
- Gastric juice in the stomach contains hydrochloric acid (about pH 2), mucus and the enzyme pepsin, which is a **protease**. The dilute hydrochloric acid:
 - stops the action of salivary amylase by denaturing it;
 - provides a low pH environment within the stomach, about pH 2, which is the optimum pH for enzyme protease to digest proteins; and
 - kills certain potentially harmful microorganisms in food.
- The protease digests proteins into polypeptides.

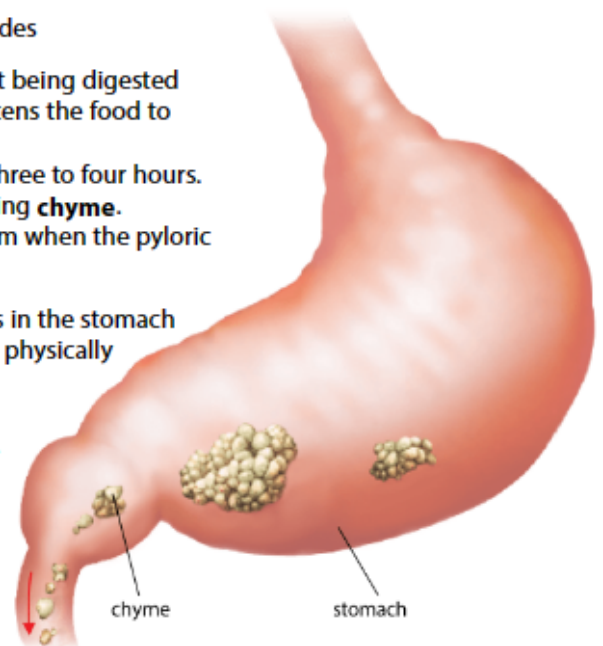


- The mucus layer protects the stomach wall against being digested by the enzymes it produces. The mucus also moistens the food to allow easy movement within the stomach.
- Food normally remains in the stomach for about three to four hours. The partly digested food becomes liquefied, forming **chyme**.
- Chyme passes in small amounts into the duodenum when the pyloric sphincter relaxes and opens (Figure 5.11).

Food stays in the stomach for a few hours. Peristalsis in the stomach helps to churn the food, which is broken down both physically and chemically.

Without the stomach, a person may not feel hungry. If a person has his stomach surgically removed because of cancer, what adjustments do you think he needs to make to his lifestyle?

Figure 5.11 Chyme passes in small amounts into the duodenum.



Past to Present

For a long time, people thought that gastric ulcers in the stomach were caused by the action of enzymes on the walls of the stomach. An Australian microbiologist, Barry Marshall, proved that gastric ulcers were in fact caused by a bacterium called *Helicobacter pylori* (*H. pylori* in short).

When Dr Marshall first proposed this hypothesis, no one believed him (Figure 5.12). He decided to do something incredibly brave to prove that his hypothesis is correct. Research on Dr Marshall's heroic attempt and find out more about his work that won him and his colleague a Nobel Prize in 2005.

Do you think his way of proving to the scientific community is an example to follow, or was he being too reckless? Explain your position as you discuss it with your friends and teacher.



Figure 5.12 The work of Dr Marshall produced an important change in the medical perception of gastric ulcers.

Processes That Take Place in the Small Intestine

Chyme enters the duodenum (Figure 5.11). It stimulates:

- the pancreas to secrete pancreatic juice. The pancreatic juice passes through the pancreatic duct into the duodenum. Pancreatic juice contains the enzymes pancreatic amylase, protease and pancreatic **lipase**.
- the gall bladder to release bile. Bile passes through the bile duct into the duodenum. Bile does not contain enzymes so it cannot digest food, but bile salts speed up the digestion of fats.
- the epithelial cells in the small intestine (Figure 5.18 on page 86) to produce the enzymes **maltase**, protease and lipase.

Food now comes into contact with pancreatic juice, bile and intestinal juice. All three fluids are alkaline. The alkalis:

- neutralise the acidic chyme; and
- provide a suitable alkaline medium (pH 8) for the action of the pancreatic and intestinal enzymes.

Digestion of Different Foods

Carbohydrate Digestion

The food we eat may contain carbohydrates such as starch, sucrose and cellulose. Carbohydrates are digested by carbohydrases such as amylase and maltase.

- Carbohydrate digestion begins in the mouth. Salivary amylase in the mouth digests starch into maltose. Only a little starch can be digested because food does not remain long in the mouth.
- No digestion of carbohydrates occurs in the stomach as there are no carbohydrases here.
- When carbohydrates enter the small intestine, they are fully digested into simple sugars. For instance, starch is digested by pancreatic amylase into maltose, which is then further digested by maltase into glucose (Figure 5.13).



Figure 5.13 Digestion of carbohydrates

The end-products of carbohydrate digestion are simple sugars which can be absorbed into the bloodstream. Cellulose is not digested at all in humans.

Protein Digestion

Proteins are digested by proteases.

- Some protein digestion begins in the stomach, where stomach protease digests proteins to polypeptides.
- The undigested proteins that enter the small intestine are digested by intestinal protease to polypeptides.
- The polypeptides produced are further digested to amino acids by intestinal protease.

The end-products of protein digestion are thus amino acids, which can be absorbed.

Figure 5.14 shows the breakdown of a protein into amino acids.

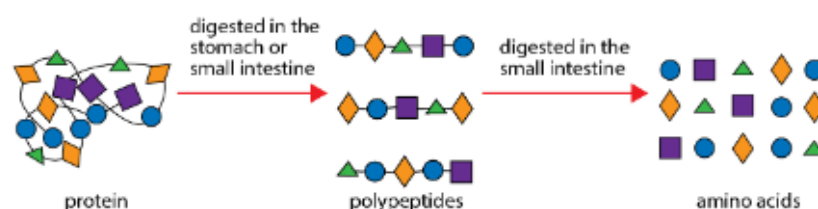


Figure 5.14 Breakdown of proteins to amino acids

Fat Digestion

Bile, produced by the liver and stored in the gall bladder, is released into the duodenum. In the small intestine, bile salts emulsify fats. They lower the surface tension of the fats, that is, they reduce the attractive forces between the fat molecules. This causes the fats to break into tiny fat droplets suspended in water, forming an emulsion. Note that this is just a physical break-up, no chemical digestion of fat molecules has occurred. Emulsification increases the surface area-to-volume ratio of the fats, speeding up their digestion by lipase (Figure 5.15).



Figure 5.15 Bile salts emulsify fats into tiny fat droplets.

► **Emulsification** is the breaking up of fats into tiny fat droplets.

Emulsified fats are digested by lipases (pancreatic and intestinal lipases) to fatty acids and glycerol. Thus, the *end-products of fat digestion are fatty acids and glycerol*.

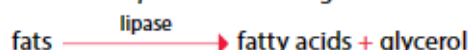


Table 5.1 summarises the chemical digestion that takes place in the digestive system.

Table 5.1 Organs and enzymes involved in digestion

Region of Digestion	Secretion	Source	Enzyme(s)	Action
Mouth	saliva	salivary glands	salivary amylase	starch → maltose
Stomach	gastric juice	gastric glands	protease	proteins → polypeptides
Small Intestine	bile	liver	-	bile salts emulsify fats
	pancreatic juice	pancreas	protease	proteins → polypeptides
			pancreatic amylase	starch → maltose
			lipase	fats → fatty acids and glycerol
	intestinal enzymes	epithelial cells	lipase protease maltase	fats → fatty acids and glycerol polypeptides → amino acids maltose → glucose



Link

Practical Workbook
Experiments 5A–5B



Let's Investigate 5.2

Aim

To demonstrate the action of bile on fats

Procedure

- 1 Fill a beaker with water.
- 2 Cover the water in the beaker with a thin layer of oil.
- 3 Sprinkle some sulfur powder into the beaker and observe the powder.
- 4 Add some detergent and observe what happens (Figure 5.16).

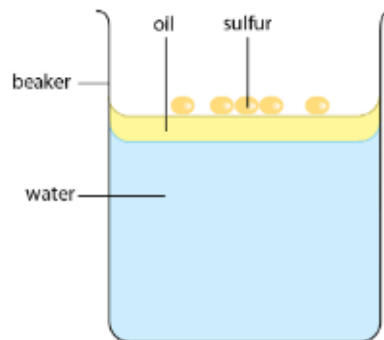


Figure 5.16

Discussion

- 1 What does the detergent represent?
- 2 What happens to the sulfur powder when the detergent is added?
- 3 What does this experiment tell you about the action of bile on fats?



Biology Connect

How are different foods digested in the human body?

Scan the QR code to review what you have learnt through an interactive animation.



Link

Theory Workbook
Worksheet 5B

Let's Practise 5.2

- 1 Protease in the stomach is released in its inactive form. It is only converted to its active form when food is present in the stomach. Suggest why protease is **not** produced in its active form.
- 2 (a) Which **three** organs produce enzymes that digest proteins?
(b) What are the final products of protein digestion?
- 3 Name the **two** glands that produce amylase.
- 4 (a) Which organ produces bile and where is bile stored?
(b) What is the function of bile?

5.3 What Is Absorption?

Learning Outcome

- Explain how the structure of a villus, including the capillaries and lacteal, is suited for its function of absorption.

Our body absorbs the necessary nutrients from the food and drink we consume. How does our body absorb these nutrients? Any undigested food is expelled from the body as faeces.

Absorption is the process whereby digested food substances are absorbed into the body cells.

Products of digestion such as simple sugars, amino acids, fatty acids and glycerol are absorbed throughout the small intestine, especially along the ileum. The absorbed nutrients diffuse from the cells of the small intestine into the bloodstream.

Water and mineral salts are absorbed by the small intestine and the colon. The small intestine absorbs most of the water that enters the alimentary canal. From the small intestine, about 1 to 1.5 litres of water pass into the large intestine daily, and the colon absorbs about 90% of that amount.

How Is the Small Intestine Adapted for Absorption?

The small intestine is well adapted for the absorption of digested products:

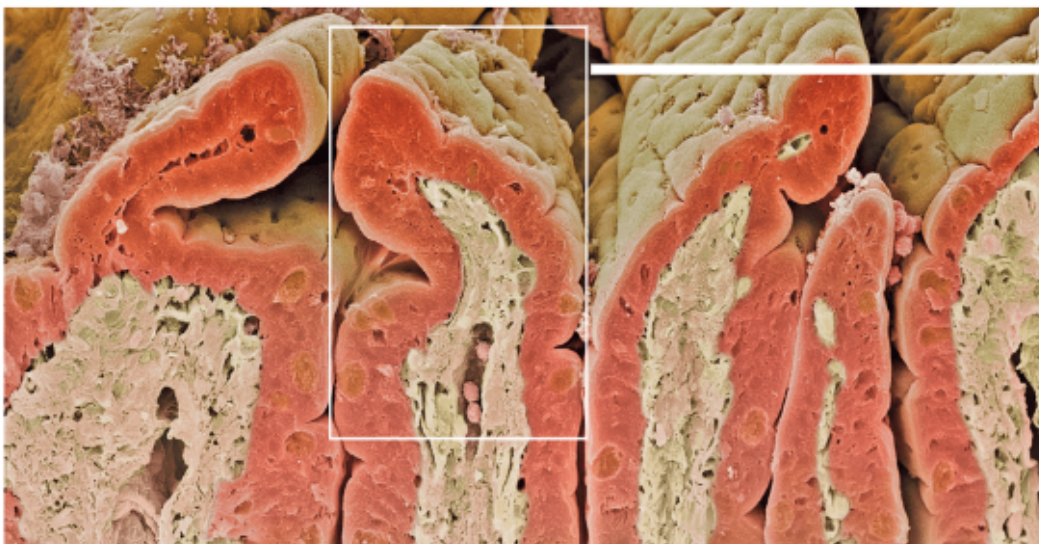
- The inner surface of the ileum is folded extensively and has numerous minute finger-like projections called **villi** (singular: **villus**) (Figure 5.17) to increase the surface area for absorption.
- The **epithelium** or wall of the villus is only one cell thick (Figure 5.18(b)) to provide a short diffusion distance for nutrients to pass through.
- The cells of the epithelium have many microvilli to further increase the surface area of the small intestine (Figure 5.18(c)).
- Each villus has many blood capillaries that allow the blood to transport the absorbed glucose and amino acids in order to maintain a diffusion gradient.
- Each villus contains a **lacteal** to transport the absorbed fats away and maintain a steep diffusion gradient.
- The epithelial cells contain many mitochondria to provide energy for active transport of nutrients into the villi.



Disciplinary Idea

Structure and Function

The various organs in the alimentary canal are adapted for the digestion, absorption and assimilation of food.



a highly magnified villus

Figure 5.17
Scanning electron micrograph of the small intestine showing the villi



Link

Active transport uses energy from respiration to transport a substance against its concentration gradient. Recall what you have learnt in Chapter 2.

How Does Absorption Take Place in the Intestines?

- Glucose and amino acids are absorbed by diffusion into the blood capillaries of the villi (Figure 5.18).
- Glucose and amino acids are also absorbed by active transport. This happens when there is a lower concentration of these digested food substances in the lumen of the small intestine than in the blood capillaries.
- Glycerol and fatty acids diffuse into the epithelium. Here they combine to form minute fat globules that enter the lacteals.

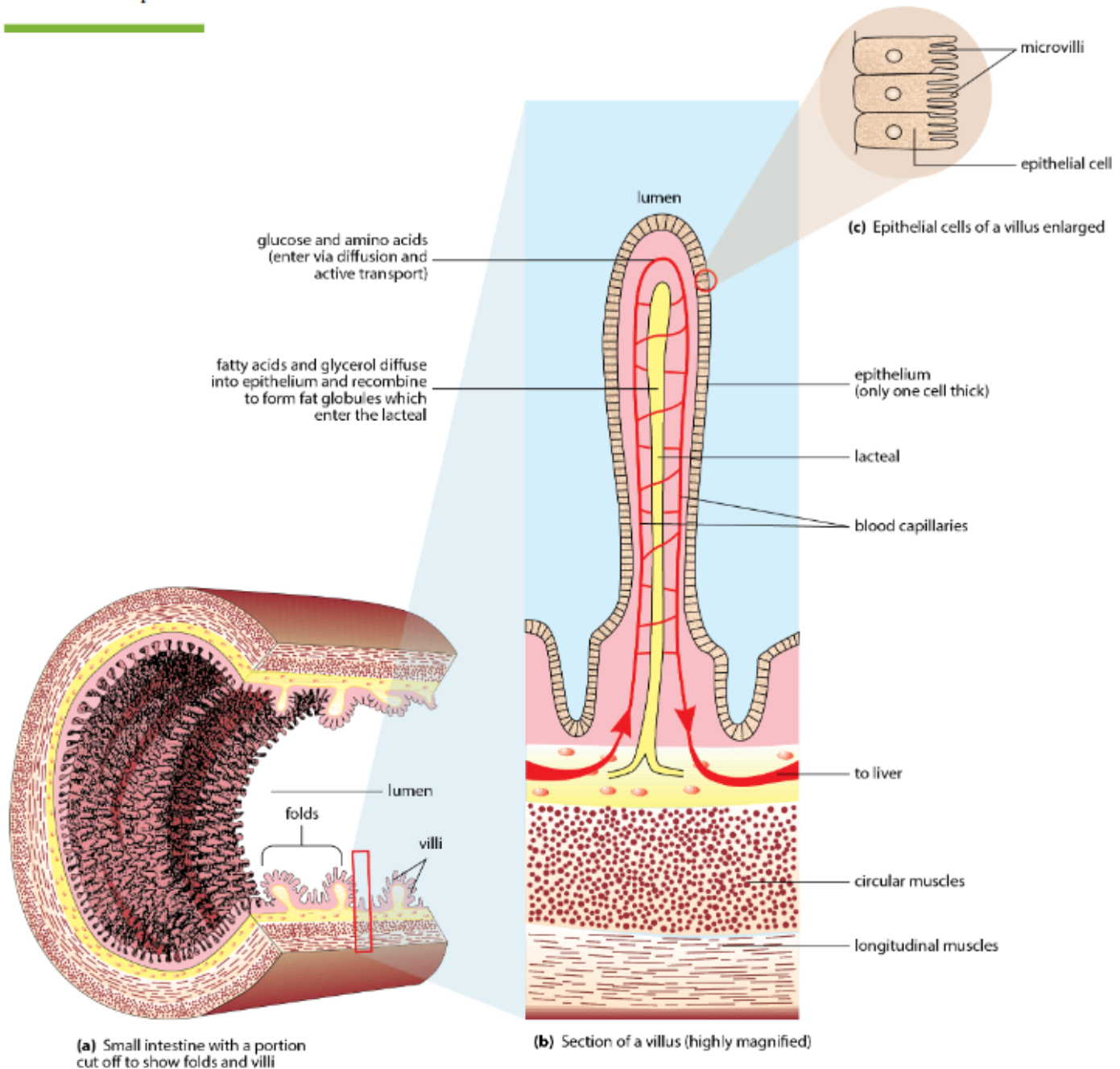


Figure 5.18 Villi in a portion of the small intestine

What Happens to Undigested and Unabsorbed Matter?

Undigested and unabsorbed matter is stored temporarily, in the rectum, before it is discharged as **faeces** through the anus. This removal of undigested matter from the body is called **egestion** or **defecation**.



Tech Connect

When a patient complains of abdominal pain, a doctor may suggest looking into the patient's stomach and colon through endoscopy. In the traditional procedure, the doctor inserts a tube, with a light and a camera at its tip, into the patient's stomach via the mouth. The instrument takes pictures of abnormal tissue growth (called polyps) and removes the growth. Similarly, doctors use a colonoscope via the patient's anus to observe the rectum and colon.

With emerging technology, capsule endoscopy has been developed. A patient swallows a capsule containing a camera, which takes pictures as it passes through the gut, and sends them to a computer (Figure 5.19).

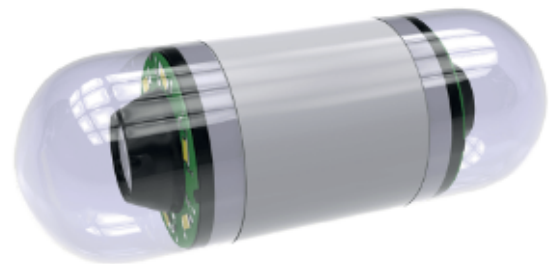


Figure 5.19 Pill-sized camera for capsule endoscopy

Which method do you think is more effective in helping the doctor know what is happening in the patient's organs? What are your reasons for saying so?

Let's Practise 5.3

- 1 Table 5.2 shows the results of the absorption of digested food substances in the presence and absence of oxygen.

Table 5.2

Digested Food Substance	Absorption In the Presence of Oxygen / Arbitrary Units	Absorption In the Absence of Oxygen / Arbitrary Units
Glucose	6.8	2.7
Amino acids	5.5	2.0
Glycerol	4.6	4.5
Fatty acids	2.0	1.9

By what processes are the digested food substances absorbed?

- 2 Based on what you have learnt about the large intestine, what do you think could cause diarrhoea?
- 3 State **three** ways in which the small intestine is adapted for the absorption of digested products.



Link

Theory Workbook
Worksheet 5C

5.4 What Happens to the Absorbed Nutrients?

Learning Outcomes

- State the function of the hepatic portal vein as the transport of blood rich in absorbed nutrients from the small intestine to the liver.
- State the role of the liver in: conversion of glucose to glycogen and vice versa, fat digestion, metabolism of amino acids and formation of urea, breakdown of alcohol, and the breakdown of hormones.

Camels can go without food or water for a long time. This is because the fat stored in their humps serve as an energy reserve. Camels that have not eaten for a while will have 'deflated' humps. In the same way, humans store fat as an energy reserve. After food is converted to forms the body can use, some go to where the nutrients are needed and some may be stored for later use. How does the body know where the nutrients should go?

► **Assimilation** is the process whereby some of the absorbed nutrients are converted into new cytoplasm or used to provide energy.

How Are Glucose and Amino Acids Transported and Utilised?

After absorption, the blood in the villi is now rich in nutrients. The blood capillaries unite to form larger blood vessels, which in turn unite to form a large vein, the **hepatic portal vein** (Figure 5.20). The hepatic portal vein transports the nutrients from the small intestine to the liver.

In the liver, most of the absorbed sugars are converted into glycogen and stored. Some glucose is transported by the blood leaving the liver and distributed around the body.

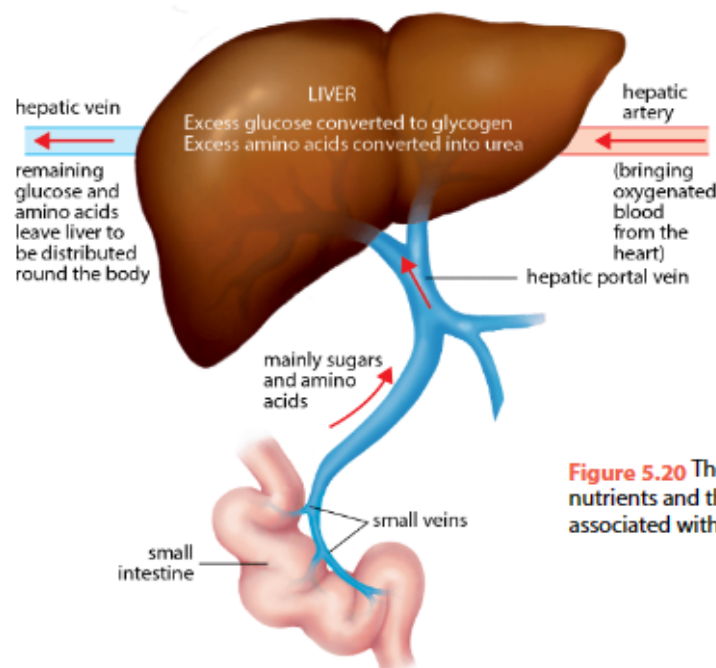


Figure 5.20 The path of absorbed nutrients and the blood vessels associated with the liver



- All cells use glucose as a source of energy. Glucose is assimilated and then broken down during tissue respiration to release energy for the vital activities of the cells.
- Excess glucose is returned to the liver and stored as glycogen. A hormone called insulin, which is produced by the islets of Langerhans in the pancreas, stimulates the liver cells to convert excess glucose into glycogen (see later in this section). When the body needs energy, the liver converts the stored glycogen back into glucose. The glucose is then transported by the blood to the cells.
- Amino acids that enter the cells are converted into new cytoplasm that is used for growth and repair of worn-out parts of the body.
- Amino acids are also used to form enzymes and hormones.
- Excess amino acids are deaminated in the liver.

How Are Fats Transported and Utilised?

Fats are absorbed into the lymphatic capillaries. The lymphatic capillaries join to form larger lymphatic vessels, which discharge fats into the bloodstream. Blood carries the fats to all parts of the body, especially the liver. Here, the fats are converted into forms that can either be broken down or stored.

- Under normal conditions when there is a sufficient supply of glucose, fats are not broken down. Instead, fats are used to build protoplasm, for example, cell membranes.
- When glucose is in short supply, for example, during fasting, fats are broken down to provide the energy needed for the vital activities of the body.
- Excess fats are stored in special tissues called **adipose tissues**, which can be found beneath the skin and around the heart and the kidneys. Adipose tissues protect these organs by acting as shock absorbers.

You have learnt how some nutrients are absorbed and assimilated into the body.

Now, consider the following snacks:

- a 200-calorie snack of peanut butter and crackers
- a 200-calorie snack of french fries
- a 200-calorie snack of sugar-coated doughnuts

The three people in Figure 5.21 have different views on which snack is best in providing a quick energy boost. Do you agree with any of the views? Why or why not?

Figure 5.21
Three friends are discussing how some snacks can provide a quick boost of energy. What is your view?



Let's Investigate 5.3 studies the digestion and absorption of carbohydrates.

Let's Investigate 5.3

Aim

To investigate digestion and absorption of carbohydrates

Procedure

- 1 Pour a solution, which contains equal concentrations of glucose and starch, into the Visking (cellulose) tubing provided. Ensure that none of the liquid has spilled on the outside of the tubing.
- 2 Tie the open end of the tubing with cotton thread.
- 3 Rinse the outside of the tubing with water and then place it in the large test-tube or boiling tube containing distilled water as shown in Figure 5.22.
- 4 Immediately, using a pipette, remove a little of the distilled water surrounding the Visking tubing.
 - (a) Place a drop of this sample onto a white tile and add a drop of iodine solution.
 - (b) Use the remainder of the sample to test with Benedict's solution.
- 5 Repeat tests (a) and (b) in step 4 after 5, 10 and 20 minutes. Before each test, rinse the pipette thoroughly.
- 6 Record your observations in Tables 5.3 and 5.4.
- 7 Write down your deductions.

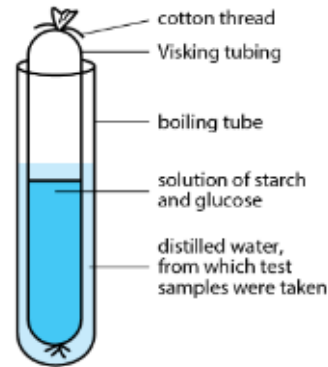


Figure 5.22

Table 5.3

Iodine Test	0 min	5 mins	10 mins	20 mins
Observation				
Deduction				

Table 5.4

Benedict's Test	0 min	5 mins	10 mins	20 mins
Observation				
Deduction				

Discussion

- 1 Assume that the Visking tubing represents a mammalian gut wall.
 - (a) Explain your results in terms of digestion and absorption of carbohydrates in the mammalian gut.
 - (b) Name **two** enzymes involved in carbohydrate digestion and state the part of the gut in which they can be found.
 - (c) If the Visking tubing represents a portion of the mammalian gut, what would the distilled water represent?

What Are the Functions of the Liver?

The liver is the largest organ in the human body. A damaged liver may cause many problems. What important functions does the liver have?

The liver has many other important functions apart from its role in digestion. It is the major organ involved in regulating the levels of various substances in the body.

Production of Bile

The liver also plays an important role in fat digestion. It helps in the digestion of fats by secreting bile. Bile is stored temporarily in the gall bladder before use.

Deamination of Amino Acids

Excess amino acids are transported to the liver. Their amino groups are removed and converted into **urea** (Figure 5.23). This is called **deamination**.

► **Deamination** is the process by which amino groups are removed from amino acids and converted to urea.

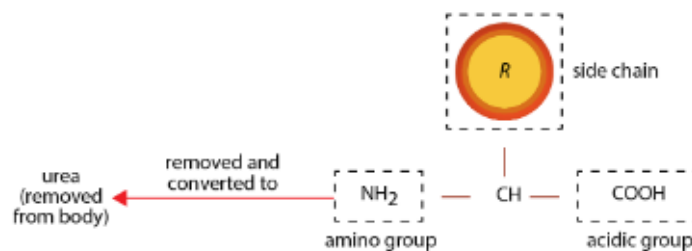


Figure 5.23 Amino group is removed and converted to urea in a deamination process.

Urea is removed from the body in the urine. The remains of the deaminated amino acids are converted into glucose in the liver. Any excess glucose formed in this way is converted into glycogen.

Regulation of Blood Glucose Concentration

The liver plays a key role in carbohydrate metabolism by keeping the amount of glucose in the blood constant, especially after a heavy meal or during fasting (Figure 5.24). The pancreas contains special groups of cells known as the islets of Langerhans which secrete the hormones insulin and glucagon into the bloodstream. Both insulin and glucagon together help to regulate the level of glucose in the blood.

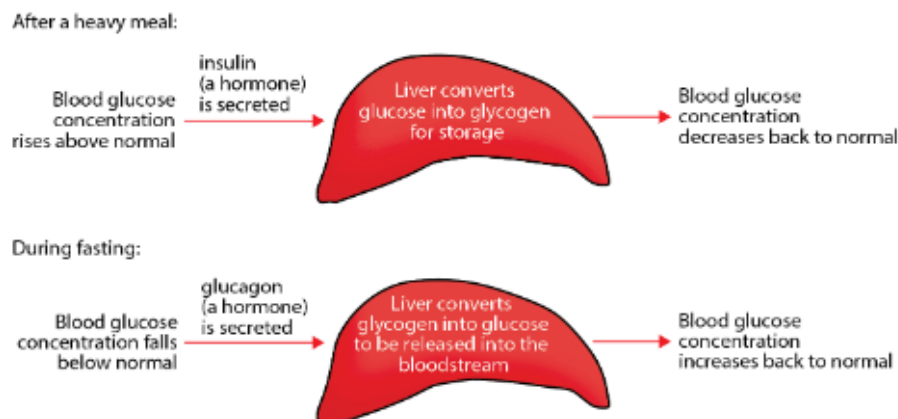


Figure 5.24 Carbohydrate metabolism in the liver



Link

How is urea removed from the body? Read more about this in Chapter 8.



Link

How is blood glucose kept constant? Read more about it in Chapter 9.



Link

Chemistry

We learn that ethanol is used to make alcoholic drinks. Ethanol is part of a homologous series of organic compounds called alcohols, which have the hydroxyl ($-OH$) functional group.



Link

Theory Workbook
Worksheet 5D

Breakdown of Hormones

Hormones, after they have served their purpose, are broken down in the liver.

Detoxification

Harmful substances may be absorbed into the blood from the gut. These substances (e.g. the food preservative benzoic acid) are made harmless by the liver cells. The process of converting harmful substances into harmless ones is known as **detoxification**.

Alcohol is another example of a harmful substance that is broken down by the liver. Alcohol can cause damage to the digestive system and slow down brain functions. Liver cells contain an enzyme which breaks down alcohol to compounds that can be used in respiration, providing energy for cell activities.

Let's Practise 5.4

- 1 What is the function of the hepatic portal vein?
- 2 Where is fat first absorbed?
- 3 What are adipose tissues? What are their functions?
- 4 What part is played by the liver in the digestion of food?
- 5 State the role of the liver in carbohydrate metabolism and detoxification.

5.5 What Are the Effects of Alcohol Consumption?

Learning Outcome

- Outline the effects of alcohol consumption on the brain (e.g. increased reaction time, reduced self-control), the long-term effects of excessive consumption (e.g. liver disease and brain damage) and the social implications.

Some people drink alcohol to relax, but excessive alcohol consumption may have harmful effects. It can cause damage to the digestive and nervous systems. There is also significant impact on society.

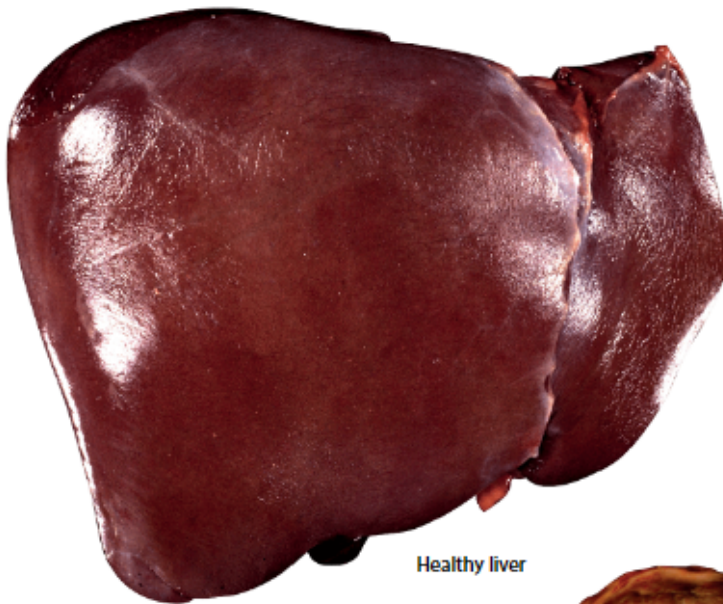
Harmful Effects on the Digestive System

Alcohol stimulates acid secretion in the stomach. Excess stomach acid increases the risk of gastric ulcers. Prolonged alcohol abuse may lead to **cirrhosis** of the liver (Figure 5.25). Cirrhosis is a disease in which the liver cells are destroyed and replaced with fibrous tissue, making the liver less able to function. Patients with alcoholic cirrhosis may **haemorrhage** in the liver. This can lead to liver failure and subsequently, death.

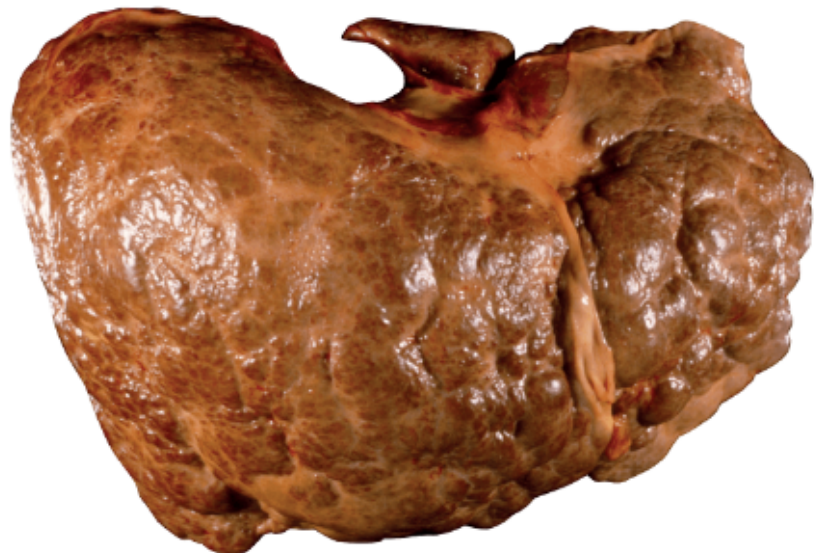


Word Alert

Haemorrhage: undergo heavy bleeding



Healthy liver



Liver cirrhosis

Figure 5.25 Comparing a healthy liver and a liver with cirrhosis

Harmful Effects on the Nervous System

Depressant

Alcohol is a depressant. It slows down some brain functions. Its effects vary from one person to another.

Reduced Self-control

Under the influence of alcohol, a person becomes carefree as alcohol takes away his self-control. With his self-control reduced, he may do things that he may regret after the effects of alcohol have worn off.

Effect on Reaction Time

As the person drinks more alcohol, other observable effects of intoxication, such as slurred speech, occur. Blurred vision and poor muscular coordination make him clumsy and unable to walk steadily. His judgement deteriorates and he tends to underestimate speed.

If he drives, he may drive faster and with less caution and his reactions become slower. Drunk drivers have a higher tendency to be involved in traffic accidents.

Long-term Effects of Alcohol Consumption on the Brain

Heavy drinking of alcohol over a long period can have long-term effects on the brain. Figure 5.26 shows the abnormal MRI scan of a chronic alcoholic.

- 'Wet brain': This is a type of dementia caused by brain damage. Alcohol interferes with the absorption of vitamin B1 (thiamine) in the small intestine. Vitamin B1 is part of an enzyme needed to break down sugar to release energy for brain activities, e.g. in the conduction of nerve impulses.
- Shrinkage of brain volume: The brain becomes smaller than normal, especially the region associated with memory and reasoning.
- Heavy consumption of alcohol during pregnancy may interfere with the development of the fetus' brain, which may lead to lifelong physical, mental and behavioural problems.



Figure 5.26 MRI scan showing a reduction in the size of the brain (indicated in red)

Social Implications

When a person drinks alcohol frequently, he can become addicted to alcohol. He is unable to stop drinking until he is drunk. His body becomes dependent on alcohol and he becomes an alcoholic. Alcoholics may cause a lot of problems to society:

- They may neglect their work and families.
- They may exhibit violent behaviour, especially towards family members.
- People under the influence of alcohol may tend to commit crimes.



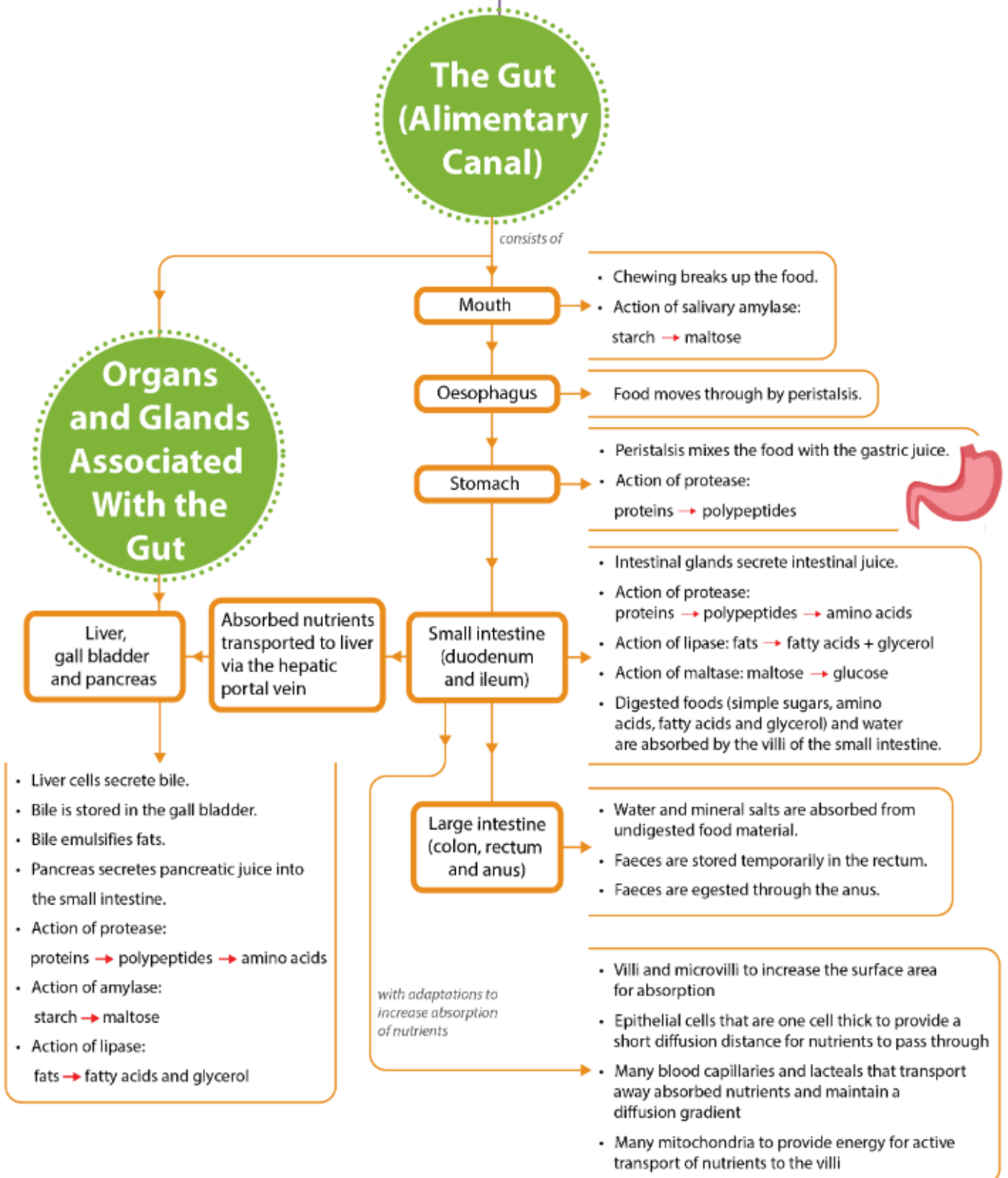
Link

Theory Workbook
Worksheet 5E
Let's Assess
Let's Reflect

Let's Practise 5.5

- 1 What can happen when a person drinks too much alcohol?
- 2 What impact does alcohol addiction have on society?

Let's Map It



Let's Review

Section A: Multiple-choice Questions

- 1 Which **two** statements correctly describe what happens in the mouth?
- 1 Amylase breaks down starch molecules into maltose molecules.
 - 2 Chewing breaks up large insoluble molecules into small soluble molecules.
 - 3 Chewing increases the surface area of food for digestion.
 - 4 Saliva emulsifies fats into minute fat globules.

- ☐ A 1 and 2
☐ B 1 and 3
☐ C 2 and 3
☐ D 3 and 4

- 2 Figure 5.27 shows part of the digestive system.

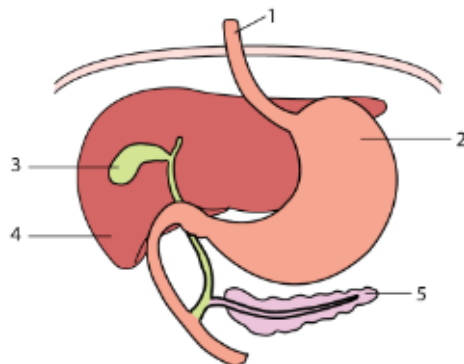


Figure 5.27

Which **two** structures produce substances involved in the digestion of fat?

- ☐ A 1 and 2
☐ B 1 and 4
☐ C 2 and 3
☐ D 4 and 5

Section B: Structured Questions

- 1 The effects of pH on the activity of three different enzymes, A, B and C, in the human body are shown in Figure 5.28.

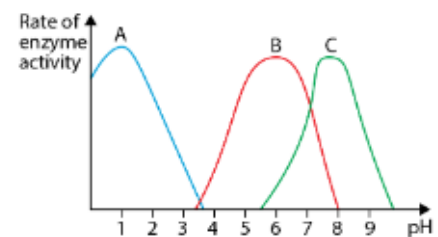


Figure 5.28

- (a) Which enzyme, A, B or C, is produced in
- (i) the duodenum; and
 - (ii) the stomach?
- (b) Give reasons for your answers in (a).
- 2 Papaya contains an enzyme that can be used to make meat more tender. It should be added to the meat a few hours before, rather than during cooking. Explain why.
- 3 Figure 5.29 shows a blood vessel (B), joining a part of the alimentary canal (A) to an organ (C) in the abdomen.

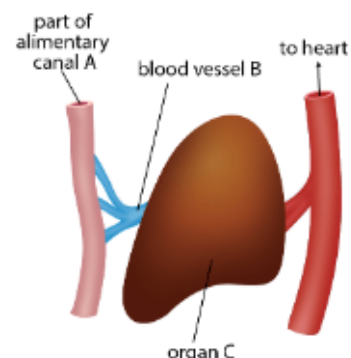


Figure 5.29

- (a) Identify A, B and C.
- (b) State the changes in the composition of the blood shortly after a meal rich in proteins and starch.

Section C: Free-response Question

- 1 Explain why motorists are often advised "If you drink, don't drive; if you drive, don't drink".

CHAPTER

06 Transport in Humans



What You Will Learn



- What are the components of blood?
- What are blood groups?
- How are blood vessels adapted to their functions?
- How does blood circulate in the human body?
- What is coronary heart disease?

The cyclist in the photo is training in a high-altitude room. It is a room that is specially designed to mimic the conditions at high altitudes. In this room, the level of oxygen in the air is made lower than that at sea level.



Do you know that the Singapore Sports Institute has a high-altitude room? It is used for training by our athletes in the weeks or months before a major competition.

How do you think this can help our athletes perform better?

6.1 What Are the Main Components of Blood?

Learning Outcome

- State the components of blood and their roles in transport and defence:
 - plasma: transport of blood cells, ions, soluble food substances, hormones, carbon dioxide, urea, vitamins, plasma proteins
 - red blood cells: haemoglobin for oxygen transport
 - white blood cells: phagocytosis, antibody formation and tissue rejection
 - platelets: fibrinogen to fibrin, causing clotting

Mankind has always considered blood to be a symbol of life. When an injured person has lost a lot of blood, a blood transfusion is necessary. What is the significance of this amazing substance, and what is in it?

In a simple unicellular organism (Figure 6.1), no part of the cell is far from the external environment. Oxygen and nutrients can diffuse through the cell membrane and easily reach all parts of the cell. Similarly, waste products can be rapidly removed from the cell by simple diffusion.

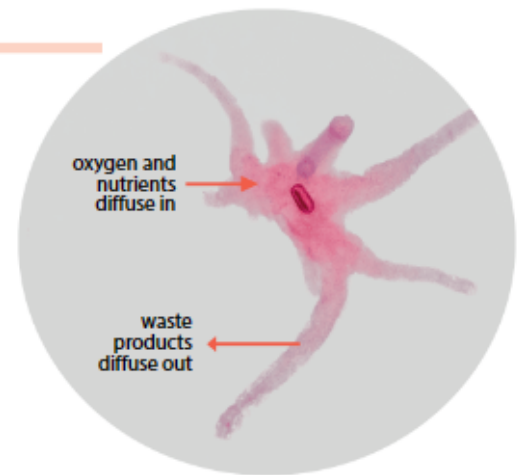


Figure 6.1 A highly magnified unicellular organism

In complex multicellular organisms such as humans and other mammals, however, numerous cells are found deep in the body, far from the external environment. Simple diffusion alone cannot bring enough oxygen and food materials to these cells in time. It also cannot remove waste products with sufficient speed. There must be a **transport system** to carry substances from one part of the body to another.

The transport system in humans, also known as the circulatory system, consists of:

- a series of blood vessels that run through the entire body
- blood, which flows through the vessels, carrying materials around the body
- a heart (muscular pump) which ensures that the fluid keeps flowing through the vessels

The **circulatory system** contains **blood**. Blood transports substances around the human body and defends it against diseases. Figure 6.2 shows the components of blood.



Link

How does blood flow within the body? Find out more in Section 6.3.



Figure 6.2 Components found in blood

Plasma

Plasma is the yellowish liquid in blood. It contains mainly water and substances such as glucose, salts, proteins, amino acids, fats, vitamins, hormones and excretory products such as urea. It also contains red and white blood cells.

Plasma transports:

- blood cells around the body
- nutrients from the small intestines to other parts of the body
- excretory products from organs where they are produced to excretory organs for removal
- hormones from endocrine glands to target organs

Red Blood Cells

Red blood cells (Figure 6.3) have the following features:

- circular, biconcave in shape
- no nucleus
- contain a red pigment called haemoglobin
- are flexible

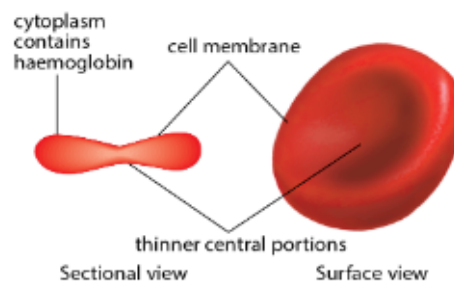


Figure 6.3 Human red blood cells

Their main function is to transport oxygen from the lungs to the other parts of the body.

To do this, they have the following adaptations:

- They contain haemoglobin that can combine reversibly with oxygen (Figure 6.4). In the lungs where oxygen concentration is high, haemoglobin binds to oxygen to form oxyhaemoglobin. In tissues where oxygen concentration is low, oxyhaemoglobin releases its oxygen to the tissue cells.

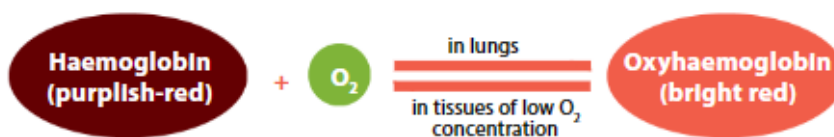


Figure 6.4 Haemoglobin combines reversibly with oxygen.

- They have a biconcave shape to increase the surface area-to-volume ratio. This increases the rate of absorption and release of oxygen.
- They are flexible and can change into a bell-shaped structure so that they can flow easily through narrow blood capillaries (Figure 6.5).
- They have no nucleus, which means there is more space for more haemoglobin to be stored.

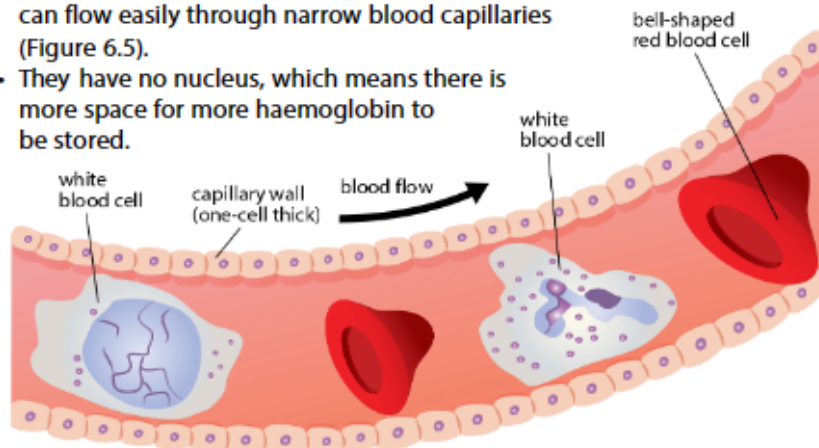


Figure 6.5 Longitudinal section of a blood capillary to show how red blood cells change their shape when flowing through



Link

Learn more about excretory products and excretion in Chapter 8.

Learn more about hormones and endocrine glands in Chapter 9.



Disciplinary Idea

Structure and Function

Blood cells are specialised cells that have special structures that are adapted to perform certain functions. Red blood cells have features that make them efficient in transporting oxygen.

Earlier, you have read about how training rooms are designed to provide similar conditions as at high altitudes. What are these conditions?

There is a lower concentration of oxygen in the air at high altitudes than at sea level. The oxygen concentration gradient between the air and the lungs is less steep. Diffusion of oxygen into the lungs is slower. Hence, less oxygen is absorbed into the bloodstream.

To compensate for this, the body responds by producing more red blood cells with more haemoglobin. This will ensure that sufficient oxygen will be available for aerobic respiration to provide enough energy to meet the body's daily activities.

So, will you train in a high-altitude training room if you are preparing for a competition?



Disciplinary Idea

Structure and Function

Blood cells are specialised cells that have special structures that are adapted to perform certain functions. White blood cells have features to perform phagocytosis and produce antibodies to fight diseases.



Word Alert

Engulfs: surrounds and covers



Link

Find out how our bodies fight diseases in Chapter 11.

White Blood Cells

There are two main types of white blood cells. These are the phagocytes and the lymphocytes (Figure 6.6).

The function of phagocytes is to perform *phagocytosis* (Figure 6.7).

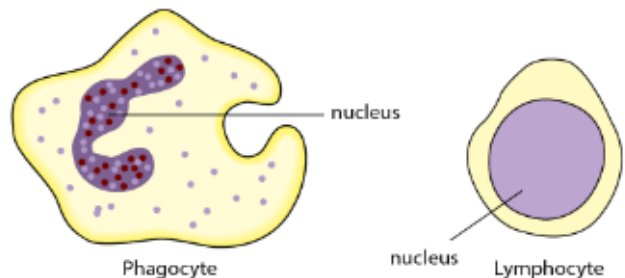


Figure 6.6 White blood cells

► **Phagocytosis** is the process by which a white blood cell **engulfs** and destroys foreign particles such as bacteria.

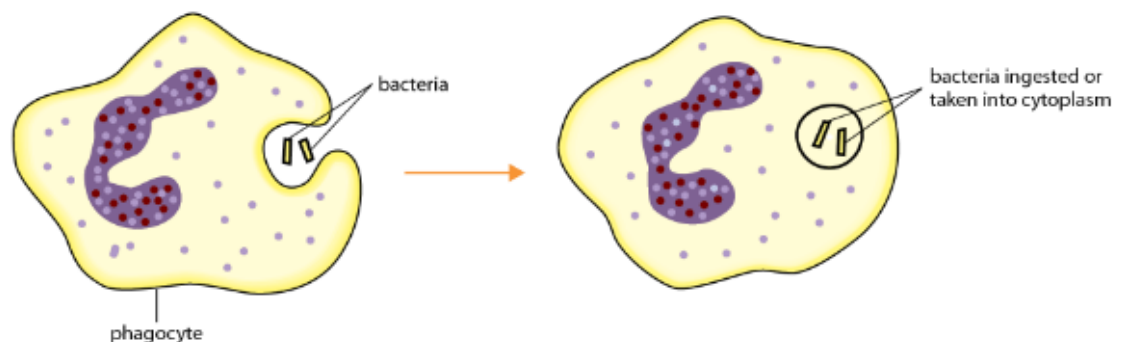


Figure 6.7 Phagocytosis

Lymphocytes produce antibodies that:

- recognise foreign particles
- destroy disease-causing organisms such as bacteria and viruses
- cause bacteria to clump together for easy ingestion by phagocytes
- neutralise the toxins produced by bacteria

White blood cells are irregular in shape. They each have a nucleus.

Platelets

Platelets are fragments of cytoplasm. They contain an enzyme that catalyses the conversion of fibrinogen to fibrin threads. These threads form a network that entangles red blood cells to form a clot (Figure 6.8). This prevents excessive blood loss and the entry of harmful organisms into the bloodstream.

How Does Blood Clot?

Blood exposed to air will soon **clot** or **coagulate**. The clot seals the wound, preventing excessive loss of blood. The clot also prevents foreign particles from entering the bloodstream. In people suffering from a hereditary disease called haemophilia, the normal blood-clotting mechanism is greatly impaired. Slight injuries, if not immediately treated, may cause such a person to bleed to death or die of internal bleeding.

The mechanism of clotting is a complicated process:

- Platelets are involved in converting the soluble protein **fibrinogen** to insoluble threads of **fibrin** (Figure 6.9). This process involves enzymes.
- Fibrin threads entangle blood cells and the whole mass forms a clot or a scab. The clot seals the wound, preventing entry of microorganisms and excessive loss of blood.

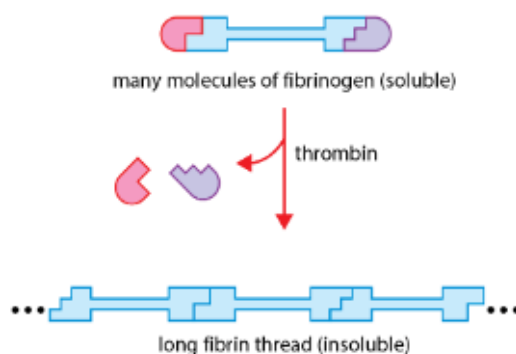


Figure 6.9 How insoluble fibrin threads are formed

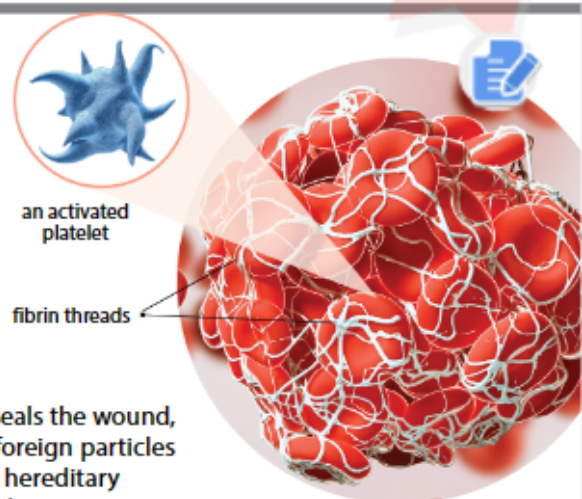


Figure 6.8 Platelets forming a blood clot



Word Alert

Coagulate: to form a solid lump; it has the same meaning as the verb *clot*, which can also be used as a noun



Helpful Note

When blood vessels are damaged, the damaged tissues and blood platelets are stimulated to release the enzyme thrombin, which is used to convert fibrinogen to fibrin.



Link

Practical Workbook
Experiment 6A

Let's Investigate 6.1

Aim

To observe the differences between a red blood cell and a white blood cell

Procedure

- 1 Examine a prepared slide of a blood smear under the microscope.
- 2 Locate one red blood cell and one white blood cell.
- 3 Make a large drawing of each cell and label the parts.

Questions

- 1 State the differences between the structures of the two cells that you observe.
- 2 State the function(s) of the two blood cells.

Organ Transplant and Tissue Rejection

You have just learnt that white blood cells in the blood react to destroy foreign particles in the bloodstream as a defence mechanism. Could this ever pose a problem for the body?

Sometimes when a person's tissue or organ is damaged or diseased, it can be replaced by a healthy tissue or organ from a donor. This is called **tissue or organ transplant**. Transplantation of organs, such as the liver, kidney and heart, has saved many lives. The organ to be transplanted must not be rejected by the recipient's immune system. Any organ from another person may be treated as a foreign body by the recipient's immune system. The recipient's white blood cells may respond by producing antibodies to destroy the transplanted organ.

Similarly, a foreign tissue may be recognised by the white blood cells. The white blood cells respond by producing antibodies to destroy the foreign tissue. This is known as **tissue rejection**. Tissue rejection will not be a problem if the tissue to be transplanted comes from the same person. For example, when a person suffers from burns to the skin, skin from an undamaged area on the same person can be used to replace the damaged skin.

If the tissue to be transplanted comes from a donor, a tissue match is necessary to reduce the risk of rejection. The tissues of both the donor and recipient must be as genetically similar as possible. Another way to reduce the risk of tissue rejection is the use of drugs which inhibit the responses of the recipient's immune system.

Let's Practise 6.1

- State the main function of the following:
 (a) a red blood cell (b) a platelet
- State the **two** main functions of the white blood cells in defending the body against diseases.
- Suggest how the following features help the red blood cell to carry out its function:
 (a) shape (b) thin cell membrane
 (c) being flexible
- What causes tissue rejection in recipients of organ transplants?



Link

Theory Workbook
Worksheet 6A



**HUMAN ORGAN
FOR TRANSPLANT**

PLEASE HANDLE WITH CARE

KEEP COOL-DO NOT FREEZE

Transport: ☐ Car ☐ Plane ☐ Ship ☐ Kidney _____
 Airport Station: _____ ☐ Liver _____
 Transfer Station: _____ ☐ Heart _____
 Flight/Train No.: _____ ☐ Lung _____

6.2 What Are Blood Groups?

Learning Outcome

- List the different ABO blood groups and describe all possible combinations for the donor and recipient in blood transfusions.

In some countries, the blood group of a person is stated in his or her identification card. This is very useful in case of an emergency. In countries, such as Singapore, where blood group tests are quick, easy, and accessible, this information is no longer included in identity cards. Why is knowing a person's blood group necessary in a medical emergency?

Large volumes of blood may be lost due to a serious injury or during a surgical operation. Long ago, people understood that if a person lost a lot of blood, it would mean death. Thus, they tried to **transfuse** blood from one person to another (Figure 6.10), often with fatal results.

Death caused by blood transfusion was due to the red blood cells of the donor **agglutinating** in the recipient's body. Such clumps blocked up small blood vessels and obstructed the flow of blood.



Figure 6.10 An 18th century doctor transfusing the blood of a man to a patient

What Are the Four Different Blood Groups?

The surfaces of your red blood cells contain special proteins called **antigens**. These same antigens are found on all of your red blood cells. Your blood plasma contains **antibodies**, which are produced by the white blood cells, and are always present in the blood. These natural antibodies will not react with the antigens on your blood cells, but they may react with the antigens on the red blood cells of another person. This causes clumping of the red blood cells (Figure 6.12).

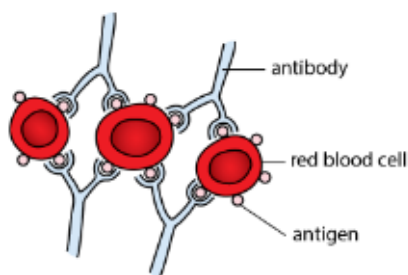


Figure 6.12 An antibody reaction with antigens on red blood cells causes **agglutination** of the cells

You can be classified into a **blood group** based on the types of antigens and antibodies present in your blood:

- The antigens are represented by capital letters A and B (e.g. antigen A, antigen B).
- Antibodies against antigens A and B may be represented by small letters a and b respectively (e.g. antibody a, antibody b).

Antibody a reacts with antigen A, and clumping occurs. A blood test can tell you which blood group you belong to.



Word Alert

Transfuse: transfer fluid (such as blood) into a vein or an artery of a person or animal

Agglutinating: clumping together

Agglutination: noun form of *agglutinate*



Cool Career

Phlebotomist

Have you heard of someone who works as a phlebotomist? Can you guess what this person does?

Phlebotomy is the process of making a puncture in the vein in order to draw blood. We see this often done in clinics or hospitals. In many countries, a person will need to obtain the appropriate professional license before he or she can practise phlebotomy.

A skillful phlebotomist is every patient's wish when it comes to drawing blood.



Figure 6.11 Phlebotomist collecting blood from a patient

There are four blood groups, named A, B, AB and O. Table 6.1 shows you the antigens and antibodies present in the different blood groups.

Table 6.1 Types of antigens and antibodies in different blood groups

Blood Group	A	B	AB	O
Red Blood Cell				
Antigen on Red Blood Cell	antigen A 	antigen B 	antigens A and B 	no antigens
Antibody in Plasma	antibody b 	antibody a 	no antibodies	antibodies a and b 



Word Alert

Agglutinate: clump together

If you belong to blood group A, your red blood cells possess antigen A and your plasma contains antibody b. Your plasma could not contain antibody a, or your own red blood cells would **agglutinate**.

What Happens When Different Blood Groups Are Mixed?

Table 6.2 summarises what will happen when different blood groups are mixed in a transfusion.

Table 6.2 Summary of reactions that occur when different blood groups are mixed

Recipient's Blood Group	Antibody in Recipient's Plasma	Donor's Blood Group			
		A (antigen A)	B (antigen B)	AB (antigens A and B)	O (no antigens: universal donor)
A	b	no clumping	clumping	clumping	no clumping
B	a	clumping	no clumping	clumping	no clumping
AB (universal acceptor)	no antibodies	no clumping	no clumping	no clumping	no clumping
O	a and b	clumping	clumping	clumping	no clumping



clumping: blood groups are incompatible



no clumping: blood groups are compatible

When you donate whole blood, it is usually separated into its components — e.g. red blood cells, plasma, platelets — for transfusion. Most of the time, only the donor's red blood cells are transfused to the recipients. The red blood cells of group O blood do not have antigens A and B. Hence, when group O red blood cells are transfused into a person of blood group A, the recipient's antibodies will not agglutinate with the donor's red blood cells. This is why a person of blood group O is called a 'universal donor'.

Now, look at what is said by each person in Figure 6.13, who is right and who is wrong? Give your reasons.



Hint

- It is safe for a recipient to receive a donor's blood if no clumping occurs when their blood is mixed.
- Refer to Table 6.2.

Figure 6.13 Two blood donors are having a discussion. Explain if each of their statements is right or wrong.

Let's Investigate 6.2

Centre for Transfusion Medicine

The Centre for Transfusion Medicine (CTM) of the Health Sciences Authority supplies blood to all hospitals in Singapore. Visit the CTM website to find out more about blood transfusion in Singapore.

- 1 Do you think you should become a blood donor in the future? Why should everyone try to become a blood donor? Discuss with your class.
- 2 A unit of blood is about 350 to 450 ml. Find out how many units of blood will be used in a year in Singapore.

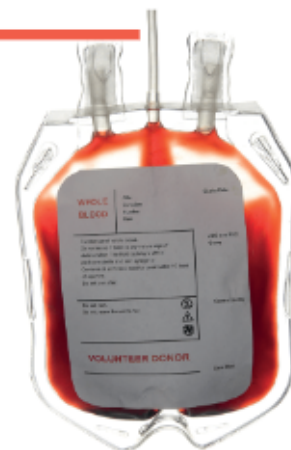


Figure 6.14 A unit of blood collected from a donor

Let's Practise 6.2

- 1 What are the different blood groups in humans?
- 2 Why is a person with blood group O a universal donor?



Link

Theory Workbook
Worksheet 6B

6.3 How Are Blood Vessels Adapted to Their Functions?

Learning Outcomes

- Relate the structures of arteries, veins and capillaries to their functions.
- Describe the transfer of materials between capillaries and tissue fluid.

Have you ever seen ships carrying cargo as they enter and leave the docks at a port? These ships go all over the world transporting goods where they are needed. They travel in an orderly manner, following fixed shipping routes over the seas. The ships and the seas are like our blood and circulatory systems, flowing in certain directions and transporting necessary materials from one part to another.

Parts of the Circulatory System

Blood is used to transport various substances from one part of the body to another by flowing continuously around the body. In vertebrates, the blood flows through a closed system of blood vessels called the **circulatory system**. This blood flow is called **blood circulation**.

Figure 6.15 shows the human circulatory system.

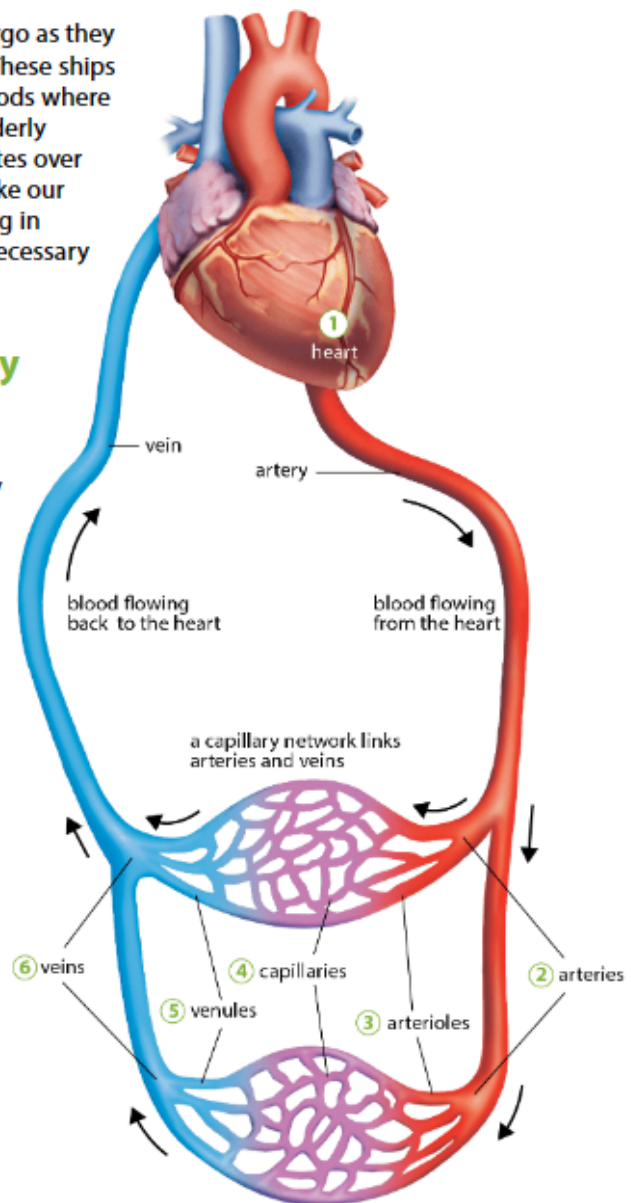


Figure 6.15 The human circulatory system



Helpful Note

Human blood is never blue. It is coloured blue in this diagram to represent deoxygenated blood.



Disciplinary Idea

Systems

The circulatory system consists of the heart, blood and a network of blood vessels that circulates blood around the body.



1 Heart

The blood is kept circulating throughout the body by means of a muscular pump, the heart. When the heart relaxes, it fills up with blood. When it contracts, the blood is squeezed out with great force. The blood then circulates through the blood vessels, which direct the blood flow around the body.

2 Arteries

The blood vessels that carry blood *away from* the heart are called **arteries**. The large artery that leaves the left side of the heart is the **aorta**. It branches to form smaller arteries.

3 Arterioles

The arteries branch to form tiny vessels called **arterioles**. The arterioles divide and ultimately, their branches become very tiny blood vessels called **capillaries**.

4 Blood capillaries

- Capillaries are microscopic blood vessels that are found between the cells of almost all the tissues. They have walls made up of only a single layer of flattened cells (Figure 6.16).

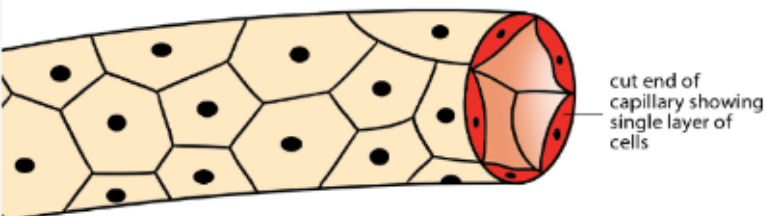


Figure 6.16 Highly magnified capillary

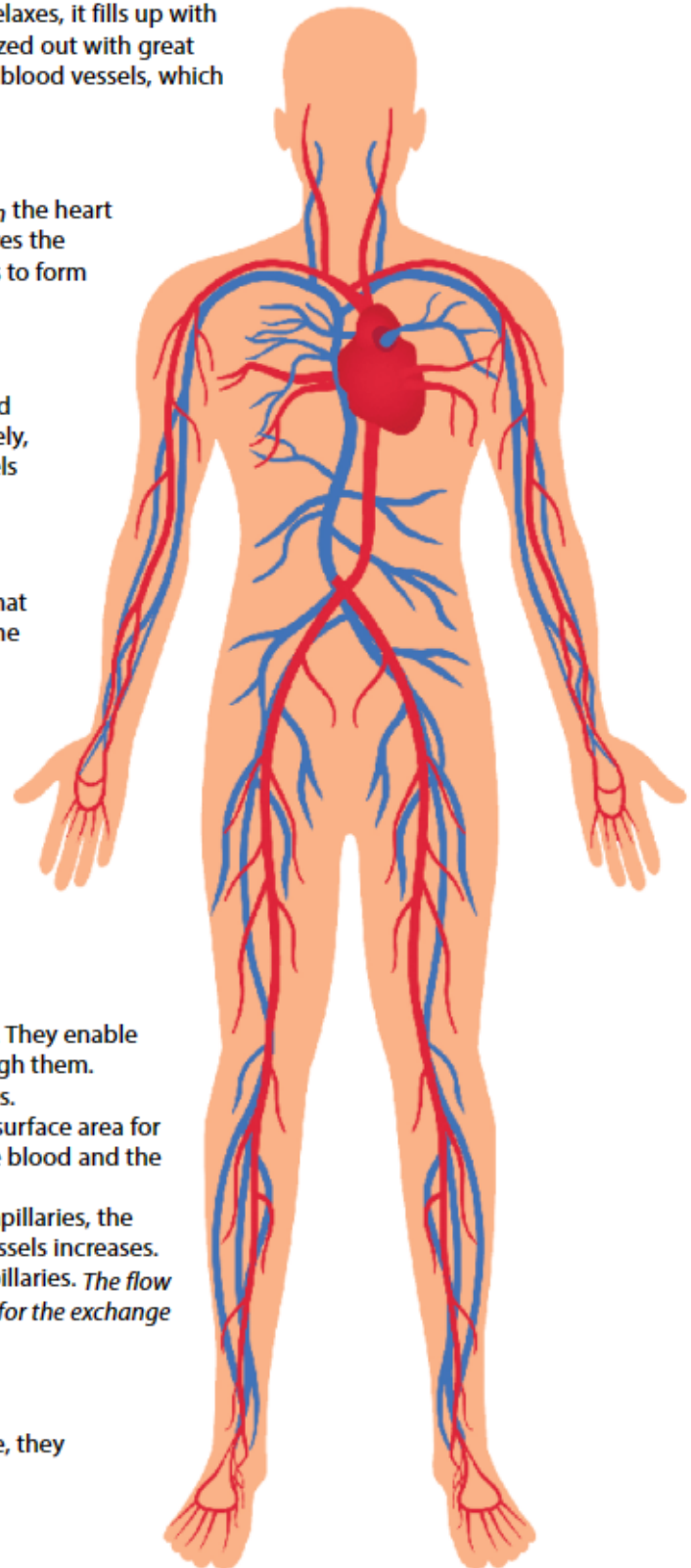
- The capillary walls are partially permeable. They enable certain substances to diffuse quickly through them.
- Small arteries branch out to form capillaries.
 - The numerous branches provide a large surface area for the exchange of substances between the blood and the tissue cells.
 - When an arteriole branches into many capillaries, the total cross-sectional area of the blood vessels increases. This lowers the blood pressure in the capillaries. *The flow of blood is slowed down, giving more time for the exchange of substances.*

5 Venules

Before the capillaries leave an organ or tissue, they unite to form small vessels called **venules**.

6 Veins

Venules in turn join to form bigger veins. **Veins** carry blood *back to* the heart.





Disciplinary Idea

Structure and Function

Arteries and veins have structures that are adapted to their functions. Arteries have thick, elastic and muscular walls to withstand high blood pressure. Veins have valves to prevent backflow of blood.

Arteries

Arteries receive blood directly from the heart. They need to be able to withstand the high pressure of the blood forced out of the heart. Blood that flows in the arteries is fast-moving. Hence, arteries have walls that are thick, muscular and elastic (Figure 6.17). The elastic layer is much thicker in the arteries nearest to the heart.

The thick elastic walls help to withstand the high blood pressure in the artery. The elasticity enables the artery wall to stretch and *recoil* or spring back. This helps to push the blood in spurts along the artery and also gives rise to the **pulse** (see Section 6.4).

The contraction and relaxation of muscles in the arterial wall bring about constriction and dilation of the artery. When an artery **constricts**, its lumen becomes narrower and less blood flows through it per unit time. On the other hand, when an artery **dilates**, its lumen becomes wider and more blood flows through it per unit time.

Arteries carry oxygenated blood (except for the pulmonary arteries which carry deoxygenated blood from the heart to the lungs). Arteries branch to form arterioles.

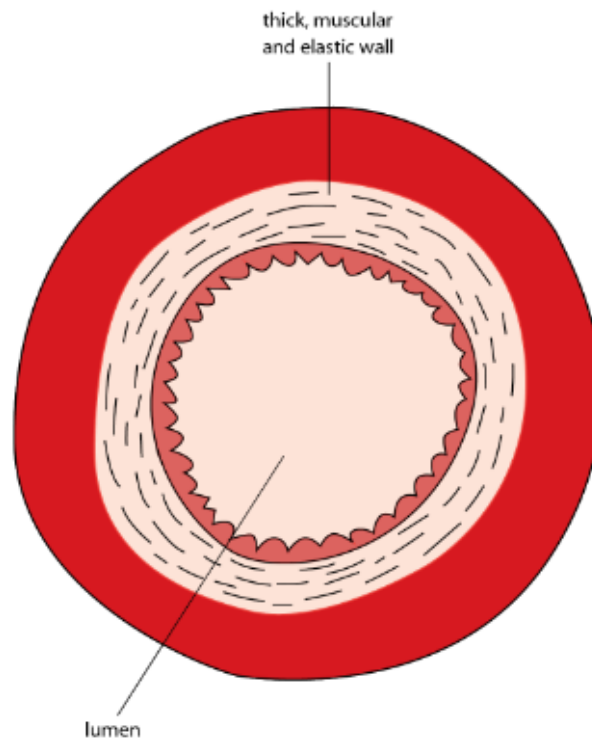


Figure 6.17 Cross-section of an artery

Veins

Veins transport blood towards the heart. The blood pressure in the veins is much lower than the blood pressure in the arteries. Blood flows more slowly and smoothly in the veins. Hence, the walls of the veins need not be as thick and muscular as those of arteries of about the same size (Figure 6.18).

Veins also contain less elastic tissue. Instead, most veins have internal **valves** along their length to prevent **backflow** of blood (Figure 6.19).

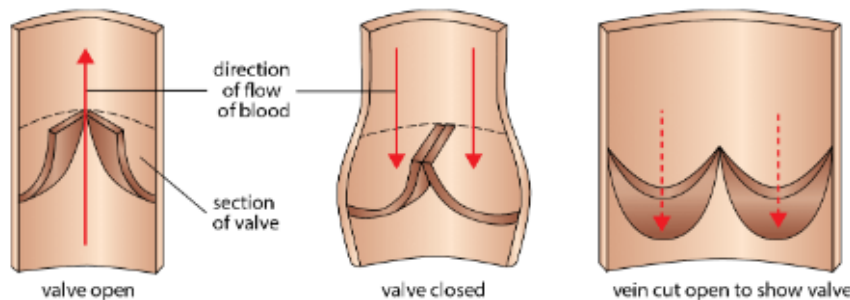
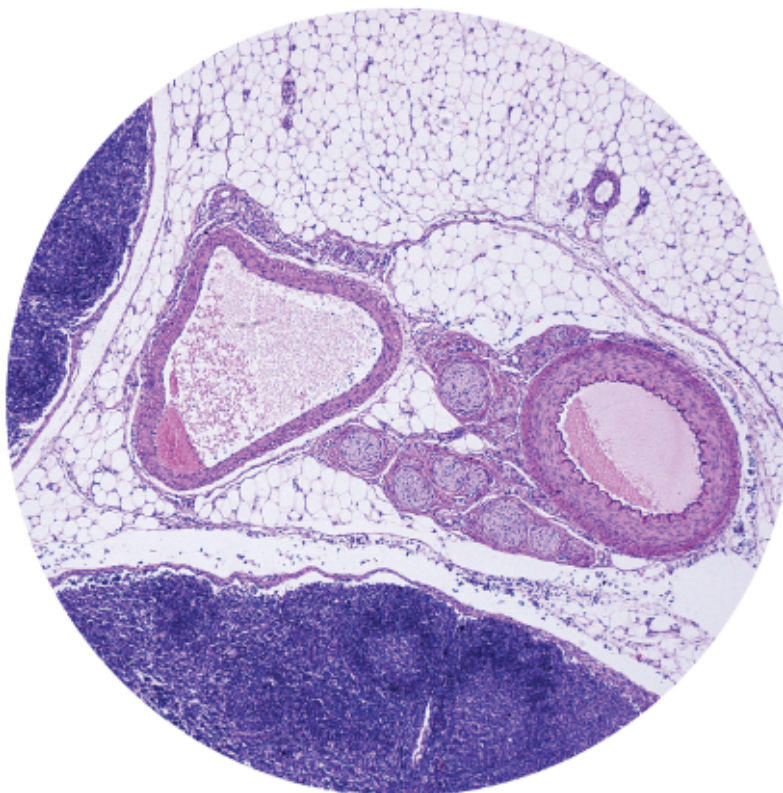


Figure 6.19 How a valve in a vein works

Figure 6.20 shows a light micrograph of a transverse section of an artery and a vein.



Veins carry deoxygenated blood (except for the pulmonary veins which carry oxygenated blood from the lungs to the heart). They are formed when venules join together.

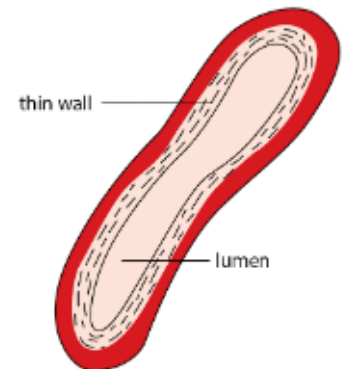


Figure 6.18 Cross-section of a vein



Word Alert

Backflow: flow that is in the backward or opposite direction



Link

Practical Workbook
Experiment 6B

Figure 6.20 This light micrograph shows a transverse section of an artery and a vein. Can you identify the artery and the vein?



Helpful Note

The movement of blood along the veins is assisted by the action of skeletal muscles on the veins. Moving the muscles increases the pressure exerted on the veins and moves the blood along more quickly (Figure 6.21).

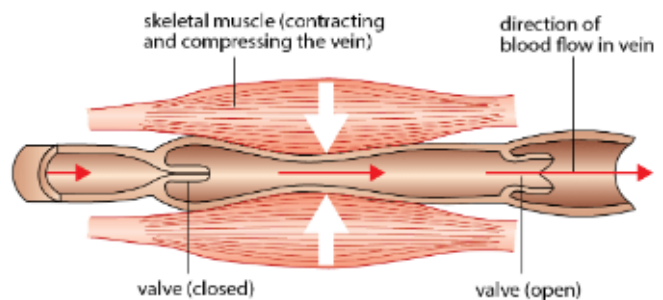


Figure 6.21 How skeletal muscles help blood flow in the vein



Helpful Note

The tissue fluid is also called the **intercellular** or **interstitial fluid**.



Link

Recall what you have learnt about diffusion in Chapter 2.



Link

Learn more about excretory waste products and excretion in Chapter 8.

How Are Substances Transferred Between Capillaries and Tissue Fluid?

The tiny spaces between tissue cells (i.e. cells that make up a tissue) contain a colourless liquid, the **tissue fluid**. This fluid transports dissolved substances between the tissue cells and the blood capillaries.

Dissolved food substances and oxygen diffuse from the blood in the blood capillaries into the tissue fluid. They then move into the cells. Metabolic (or excretory) waste products diffuse from the cells into the tissue fluid. They are then transferred through the blood capillary walls into the blood. The blood transports these waste products to the excretory organs for removal. These movements of substances are shown in Figure 6.22.

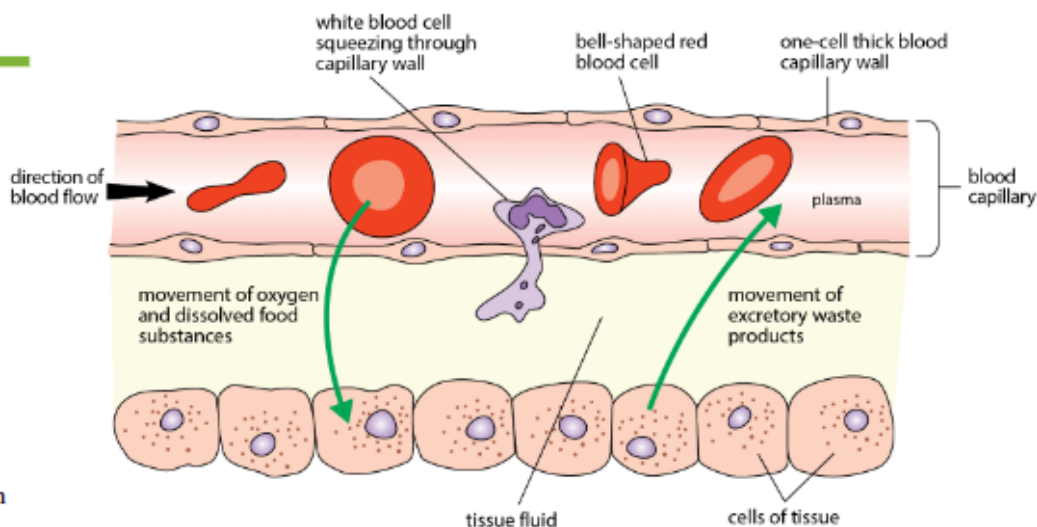


Figure 6.22 Movement of substances between the blood capillary and tissue cells via the tissue fluid

Let's Practise 6.3

- 1 What are the types of blood vessels that make up the circulatory system?
- 2 Why do arteries have thick, muscular and elastic walls?
- 3 Why do veins contain valves?
- 4 Describe the relationship among the blood capillary, tissue fluid and tissue cells.
- 5 Figure 6.23 shows the arm of a person with one vein visible on the surface. Small swellings (see points A, B, C and D in step 1) appeared along the vein. These are caused by the presence of valves.
Another person placed two fingers at point X (step 2). One finger remained at point X. The other finger stroked the vein as far as point Y and was immediately lifted. Step 3 shows what happened next.
(a) When the finger was lifted, why did the blood flow back from Y to C and no further?
(b) Why was the part of the vein between B and C no longer visible?
(c) What did this experiment demonstrate?

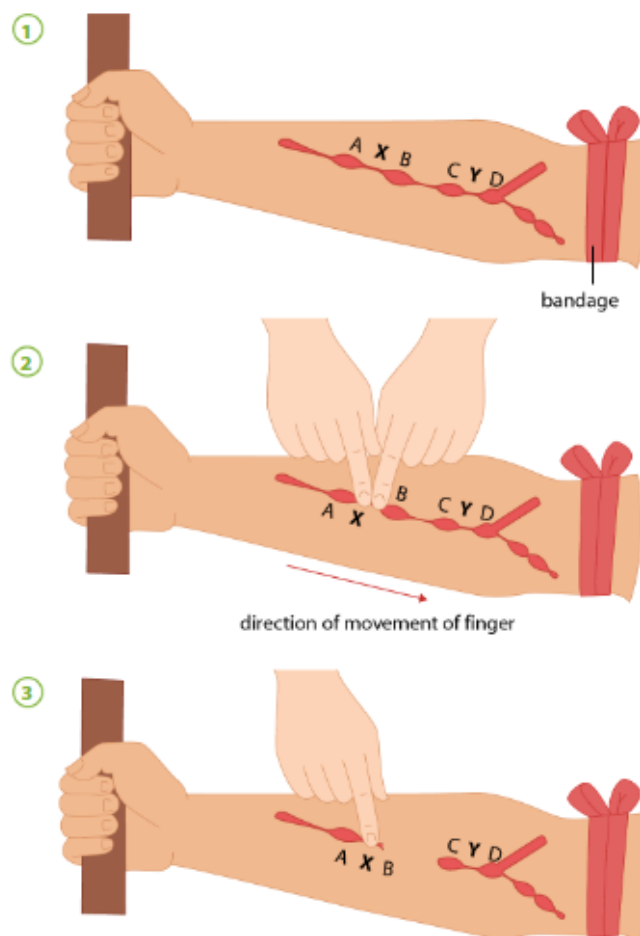


Figure 6.23



Link

Theory Workbook
Worksheet 6C

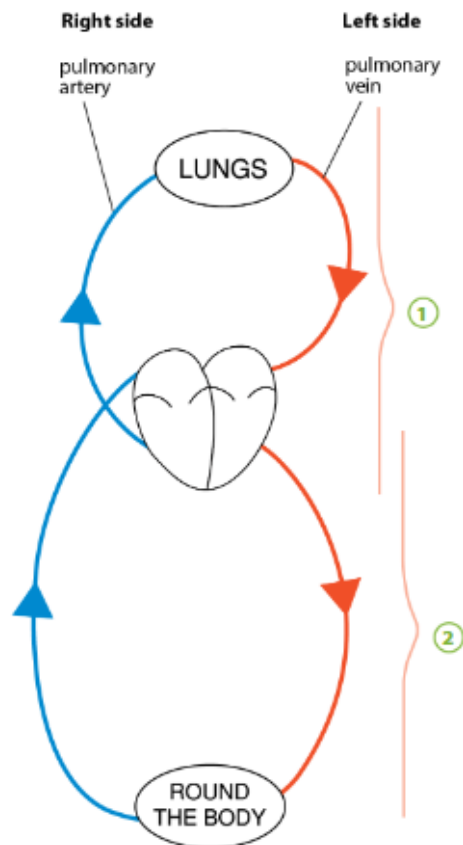
6.4 How Does Blood Circulate in the Human Body?

Learning Outcomes

- Describe the structure and function of the heart in terms of muscular contraction and the working of valves.
- Outline the cardiac cycle in terms of what happens during systole and diastole.
- Identify the main blood vessels to and from the heart, lungs, liver and kidneys.

The heart supplies the body and its organs with blood. With each beat, the heart pumps blood through the blood vessels. When you exercise, are excited, stressed, or frightened, you can feel your heart beating faster. When you relax, you can feel your heartbeat slowing down. What is going on there?

In humans and other mammals, the blood passes through the heart twice in one complete circuit (Figure 6.24). Blood flows from the other parts of the body to the heart. Then from the heart, it flows to the lungs and back to the heart again before it is pumped back to the rest of the body.



- 1 • From the heart, the **pulmonary arteries** carry blood to the lungs.
• Oxygen enters the blood at the lungs. Oxygenated blood is returned to the heart by the **pulmonary veins**.
- 2 • Oxygenated blood leaves the left side of the heart and is distributed by arteries to all parts of the body (except the lungs).
• Veins carry blood from all parts of the body back to the right side of the heart.

Figure 6.24 Blood circulation in humans

The Heart

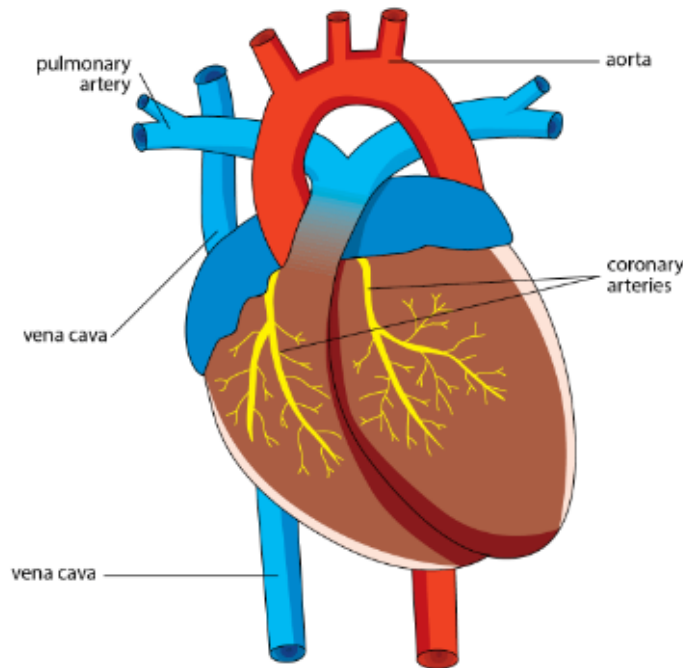
What Is the Structure of the Heart?

In humans, the heart is about the size of a clenched fist. It lies in the thorax behind the chest bone and between the two lungs. It has a roughly conical shape (Figure 6.25(a)).

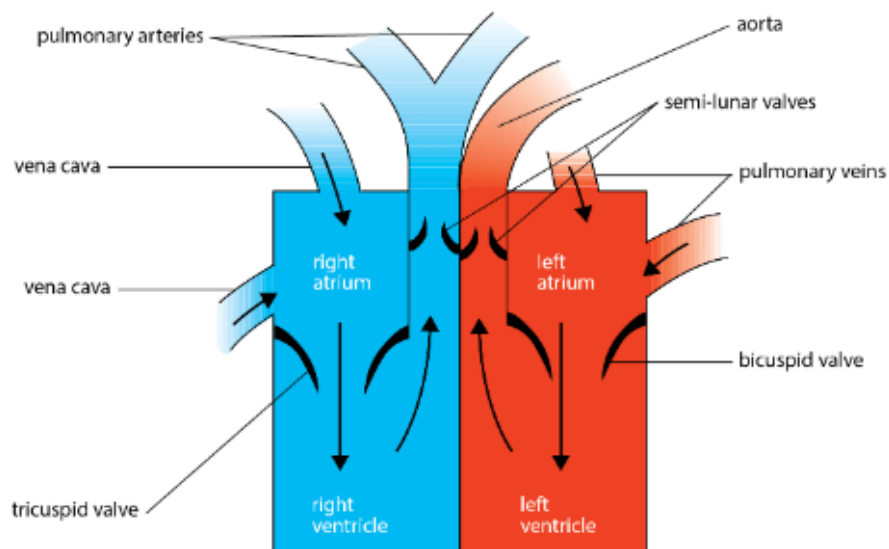


Link

Refer to Figure 7.8 in Chapter 7 to see the position of the thorax.



(a) The heart and its associated blood vessels



(b) Diagrammatic representation of the heart with the main blood vessels showing the passage of blood through the heart

Figure 6.25 Structure of the human heart



Helpful Note

When you examine a heart, the right side of the heart will be facing your left and vice versa.



Word Alert

Atrium: singular of *atria*

The human heart has four chambers. Figure 6.26 shows a more detailed diagram of the human heart that has been cut open to show the four chambers and the blood vessels. The walls of the chambers are formed by the heart muscles. When the heart muscles contract and relax, they enable the heart to pump blood around the body.

The following parts form the heart chambers:

Atria

- These are the two upper chambers — the right atrium and the left atrium.
- The atria receive blood from the veins.
- The atria have comparatively thin muscular walls, since they only force blood into the ventricles that lie directly below them. This does not require high pressure.

Ventricles

- These are the two larger lower chambers — the right ventricle and the left ventricle.
- Ventricles have comparatively thick muscular walls. The left ventricle muscle is much thicker because it pumps blood around the whole body and this requires high pressure.
- The right ventricle has thinner walls than the left ventricle since it only pumps blood to the lungs, which is close to the heart.

Median septum

- This is a muscular wall that separates the right and left sides of the heart. It runs down the middle of the heart.
- The median septum prevents the mixing of deoxygenated blood in the right side with the oxygenated blood in the left side.
- Mixing of deoxygenated with oxygenated blood will reduce the amount of oxygen carried to the rest of the body.



Disciplinary Idea

Structure and Function

The structures of the heart and its associated blood vessels facilitate the transport of blood around the body.

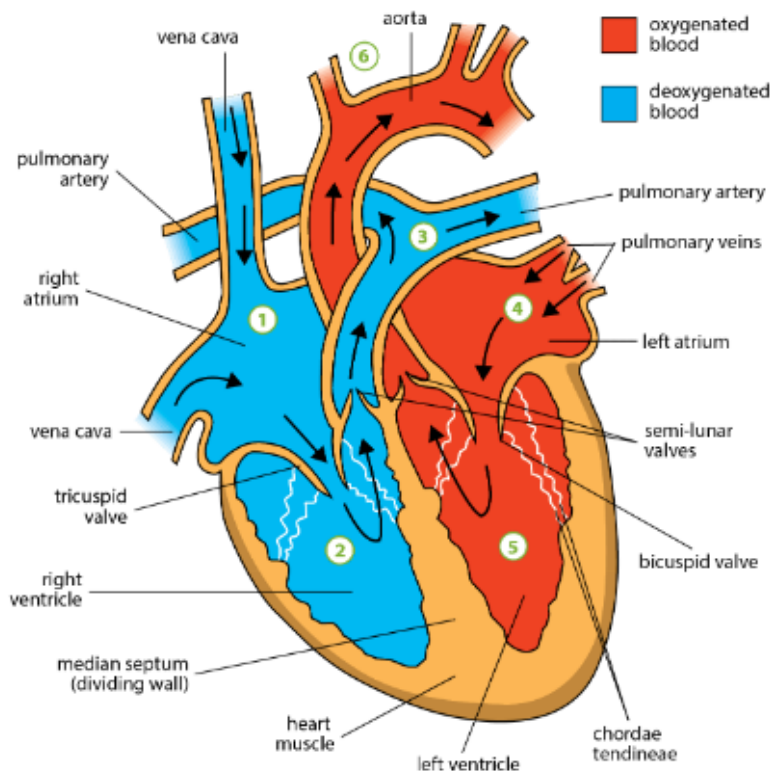


Figure 6.26 Longitudinal section of the human heart

The flow of oxygenated and deoxygenated blood through the heart is controlled by the closing and opening of valves found in the heart (Figure 6.27).

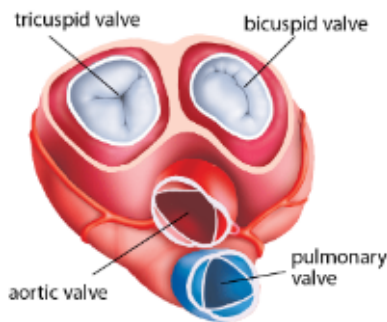


Figure 6.27 Superior (top) view of the heart

Tricuspid valve: prevents backflow of blood from the right ventricle to the right atrium

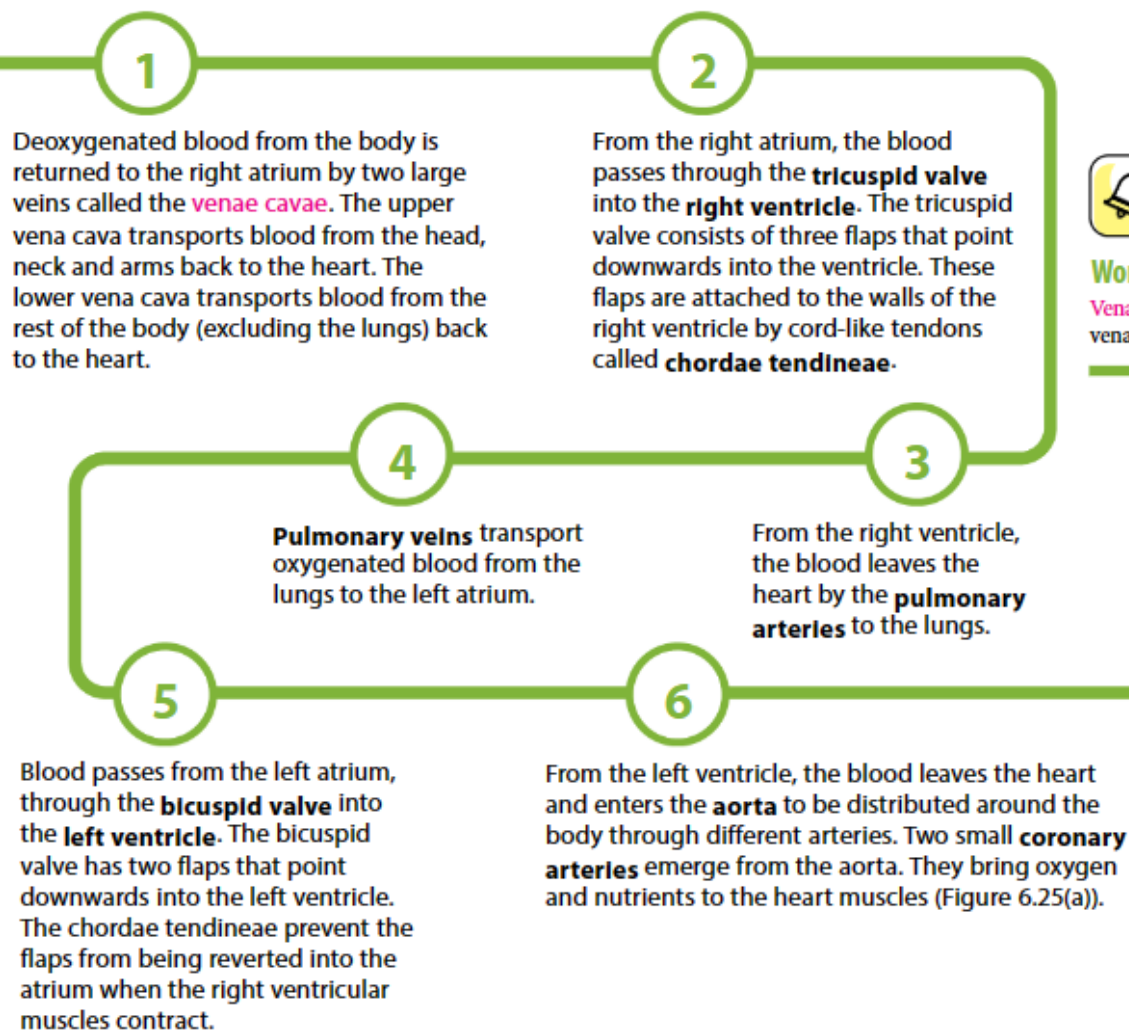
Bicuspid valve: prevents backflow of blood from left ventricle to the left atrium

Aortic valve (semi-lunar valve in the aorta): prevents backflow of blood from aorta to the left ventricle

Pulmonary valve (semi-lunar valve in the pulmonary artery): prevents backflow of blood from pulmonary artery to the right ventricle

What Paths Does Blood Take Through the Heart?

Refer to Figures 6.26 and 6.27 as you read.



What Happens When There Is a Hole in the Heart?

Some infants are born with a hole in the heart. The hole may be present in the median septum separating the left and right atria (Figure 6.28) or the left and right ventricles. Blood will flow through the hole mostly from the left side of the heart to the right side because the pressure in the left side is higher than the right side. This results in the mixing of oxygenated and deoxygenated blood, which causes less oxygen to be transported to the body cells for respiration.

Patients with this conditions may suffer from shortness of breath and fatigue, and in serious cases, heart failure may occur. However, the majority of patients do not have symptoms and do not require treatment. In more serious cases, medical treatment or surgery may be required.

RA: Right Atrium
LA: Left Atrium
RV: Right Ventricle
LV: Left Ventricle

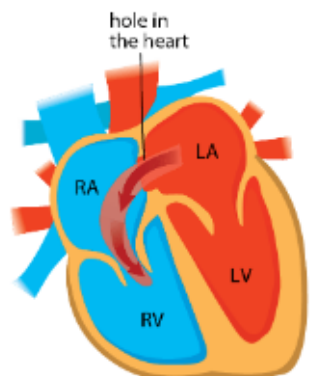


Figure 6.28 A hole in the heart results in the mixing of oxygenated and deoxygenated blood.

What Is the Cardiac Cycle?

The **cardiac cycle** refers to the sequence of events that takes place in one heartbeat (Figure 6.29).

- ① The atrial muscles contract, forcing blood into the ventricles.
- ② After a short pause, the ventricular muscles contract, causing a rise in pressure inside the ventricle. The rise in pressure causes the bicuspid and tricuspid valves to close to prevent backflow of blood into the atria. This produces a loud 'lub' sound. The semi-lunar valves open. Blood flows from the right ventricle and left ventricle into the pulmonary artery and aorta respectively.
- ③ As the ventricular muscles contract, the atrial muscles relax. The right atrium receives blood from the venae cavae while the left atrium receives blood from the pulmonary veins.
- ④ The ventricular muscles then relax. The fall in pressure causes the semi-lunar valves to close to prevent backflow of blood from the pulmonary artery and aorta into the ventricles. This produces a softer 'dub' sound. The bicuspid and tricuspid valves also open and blood flows from the atria into the ventricles.
- ⑤ The atrial muscles contract again and the whole cycle repeats.

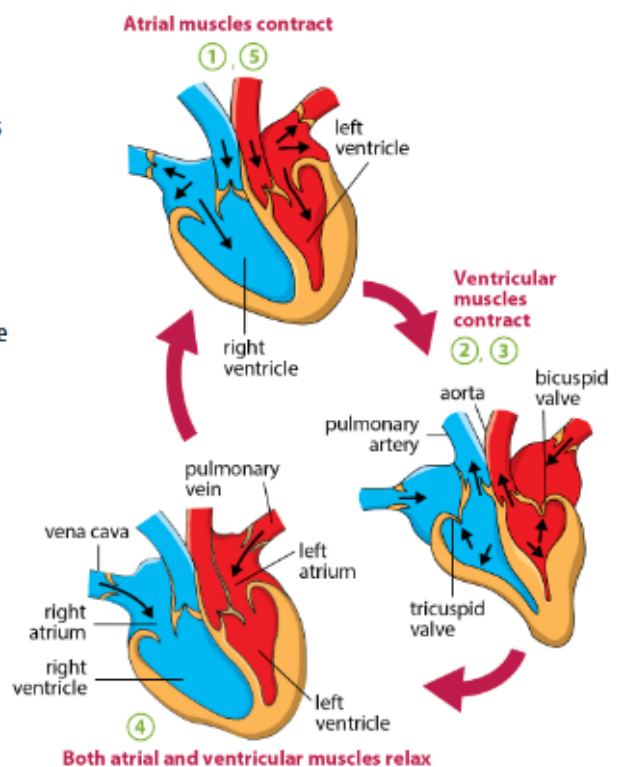


Figure 6.29 The cardiac cycle

Systole and **diastole** are the two phases of the cardiac cycle. Systole occurs when the ventricular or atrial muscles contract. Diastole occurs when the ventricular or atrial muscles relax.

A ventricular systole and a ventricular diastole make up one heartbeat. It lasts for about 0.8 seconds. There is a short pause between two heartbeats. The rate of heartbeat varies with the age and size of the individual. The average normal heartbeat of an adult is about 72 beats per minute. Note that the atria and the ventricles work alternately. When the atrial muscles contract, the ventricular muscles relax and vice versa.



Tech Connect

An electrocardiogram (ECG) is a graphical representation that can reveal important information about the heart. Some smart watches called ECG watches can measure the wearer's heart rate (how fast the heart is beating) and heart rhythm (how regular the heartbeat is). Some can even detect signs of a heart attack. These smart watches allow wearers to monitor their heart conditions any time and practically anywhere. However, it should be noted that the ECGs produced by these smart devices only give a limited view of the heart as compared to those taken at the hospital. When in doubt, it is still advisable to head to a hospital to get a thorough check.



Figure 6.30 ECG watch

How Does the Heart Control Blood Pressure?

Blood pressure is the force that blood exerts on the walls of blood vessels. It is measured in terms of millimetres (mm) of mercury.

- The blood pressure in the arteries is the highest during ventricular systole when blood is forced into the arteries.
- It decreases during ventricular diastole.

Blood pressure varies in different parts of the body. It is highest near the aorta and becomes weaker the further the arteries are away from the heart. Blood pressure is low in veins.



Figure 6.31 Nowadays, many people keep a digital blood monitoring device to monitor their blood pressure at home.



Helpful Note

Blood pressure varies from person to person. On average, systolic pressure ranges from 120–140 mm of mercury and diastolic pressure ranges from 75–90 mm of mercury (Figure 6.32). Blood pressure is given as the systolic pressure being the first number and the diastolic pressure being the second number, for example, 120/80 (read as “120 over 80”). When you get a blood pressure reading of 140/90 or higher, you are said to have high blood pressure. The condition for high blood pressure is commonly known as **hypertension**.

High blood pressure may occur temporarily after heavy exercise or when a person is angry. However, persistent high blood pressure, which may occur in middle-aged or elderly people, is a dangerous medical condition. This condition can easily be controlled if they see a doctor in time and follow the medical advice given.

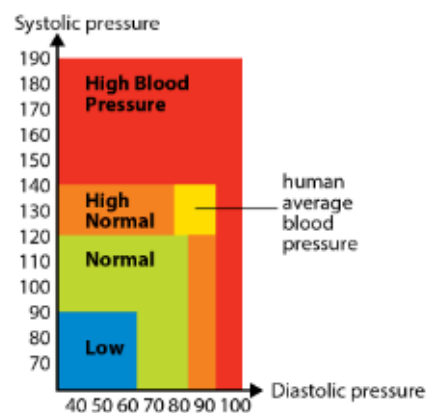


Figure 6.32 Blood pressure chart

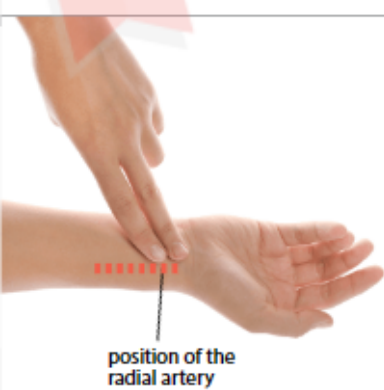


Figure 6.33 Taking the pulse

The Pulse

A pulse is produced after every ventricular contraction as the heart pumps the blood. By counting the number of pulse beats per minute (i.e. the pulse rate) (Figure 6.33), we actually get the number of heartbeats per minute (i.e. the heart rate). Even in physically healthy human beings, the pulse rate varies considerably. It is high after exertion and low during rest. However, some physically healthy people (e.g. athletes) have relatively low pulse rates.

Let's Investigate 6.3

Aim

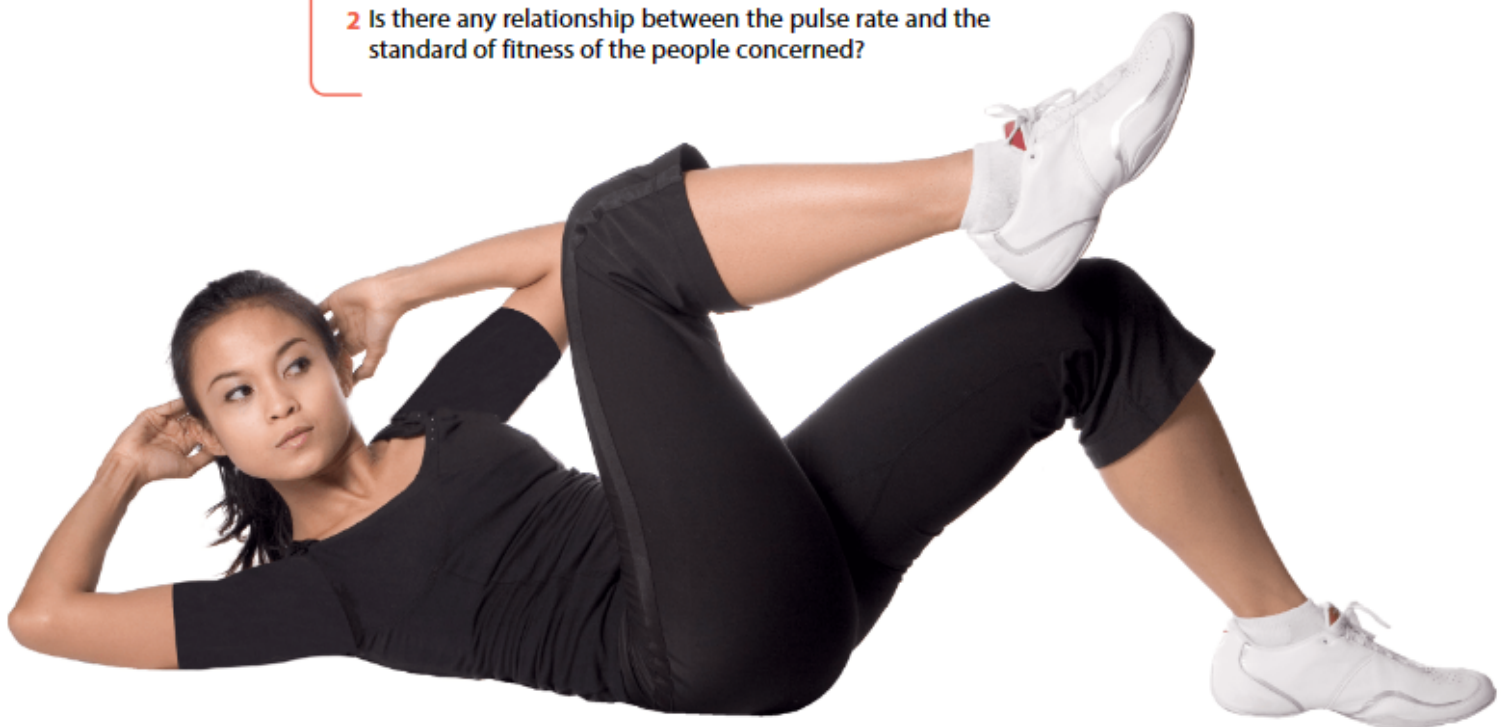
To investigate the effect of physical exercise on the pulse rate

Procedure

- 1 Feel your own pulse by placing your right fingers over your left wrist.
- 2 Count your pulse rate while you are sitting quietly. Record it in beats per minute.
- 3 Stand up slowly. After about 15 seconds, start counting your pulse. Record your pulse rate.
- 4 Do some physical exercise for 2 minutes. Then stand still and count the pulse rate for the first 5 seconds. Convert this into beats per minute. Continue recording your pulse rate every 5 seconds until your pulse rate returns to normal.
- 5 *Extension:* As a class, input your data into a shared online document. Produce a graph using a spreadsheet programme based on the data collected.

Questions

- 1 (a) Why does your pulse rate increase after running?
(b) How long does it take for it to return to normal?
(c) Compare the results between people who exercise regularly and those who do not.
- 2 Is there any relationship between the pulse rate and the standard of fitness of the people concerned?



Pressure Changes in the Heart

The graph in Figure 6.34 shows the changes in the pressure in the left side of the heart. Follow the descriptions from 1 to 8 to understand the pressure changes in the left ventricle in one heartbeat.

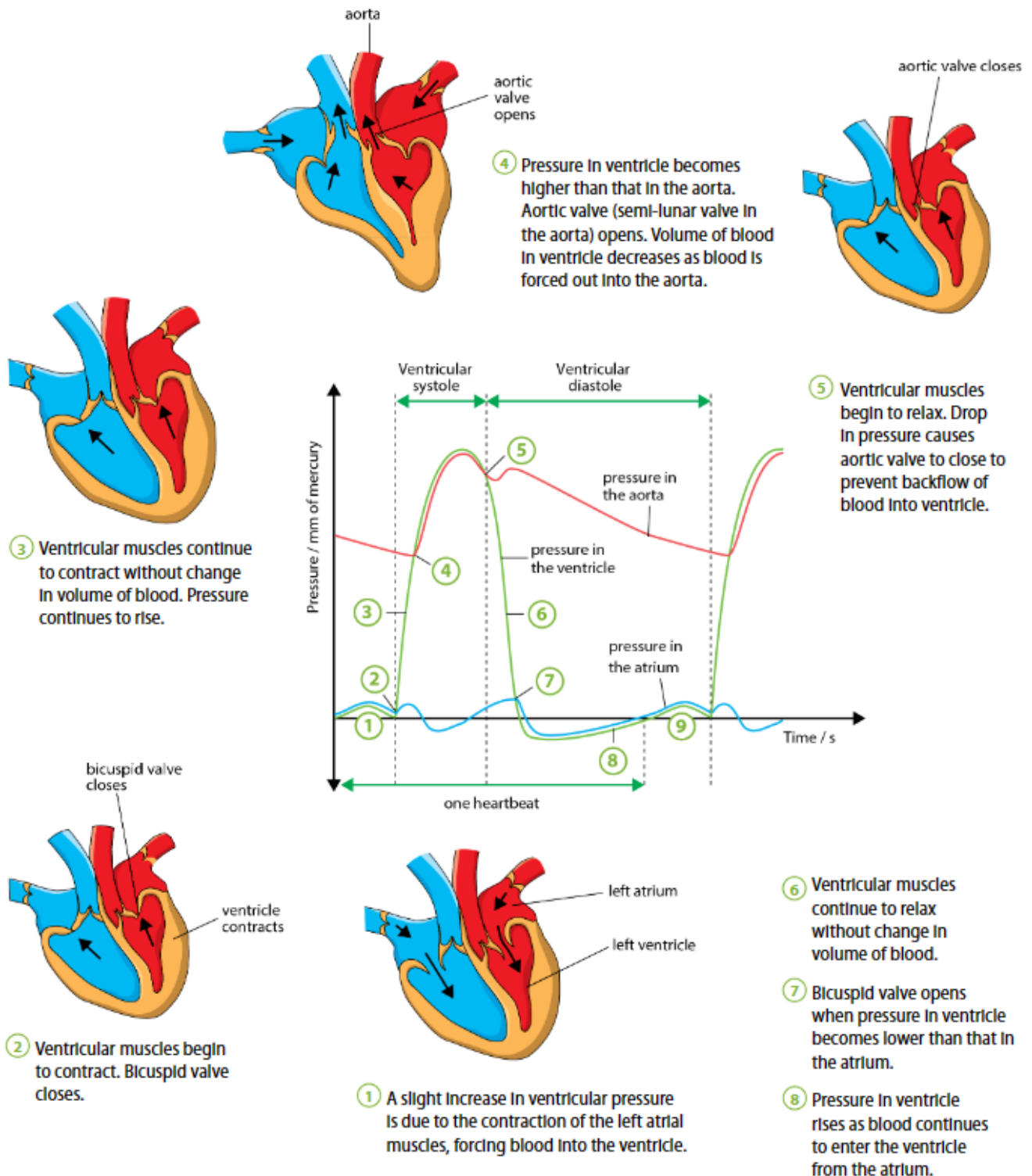


Figure 6.34 Pressure changes in the left ventricle

What Are the Main Blood Vessels Through Which the Heart Pumps Blood?

The Main Arteries of the Body

Refer to Figure 6.35 as you read.

The arteries leaving the heart are:

- the pulmonary arteries from the right ventricle
- the aorta from the left ventricle

From the aorta, the following arteries arise:

- arteries to the head, neck and arms
- the **hepatic artery** to the liver
- artery to the stomach and intestines
- the **renal arteries**, one to each kidney

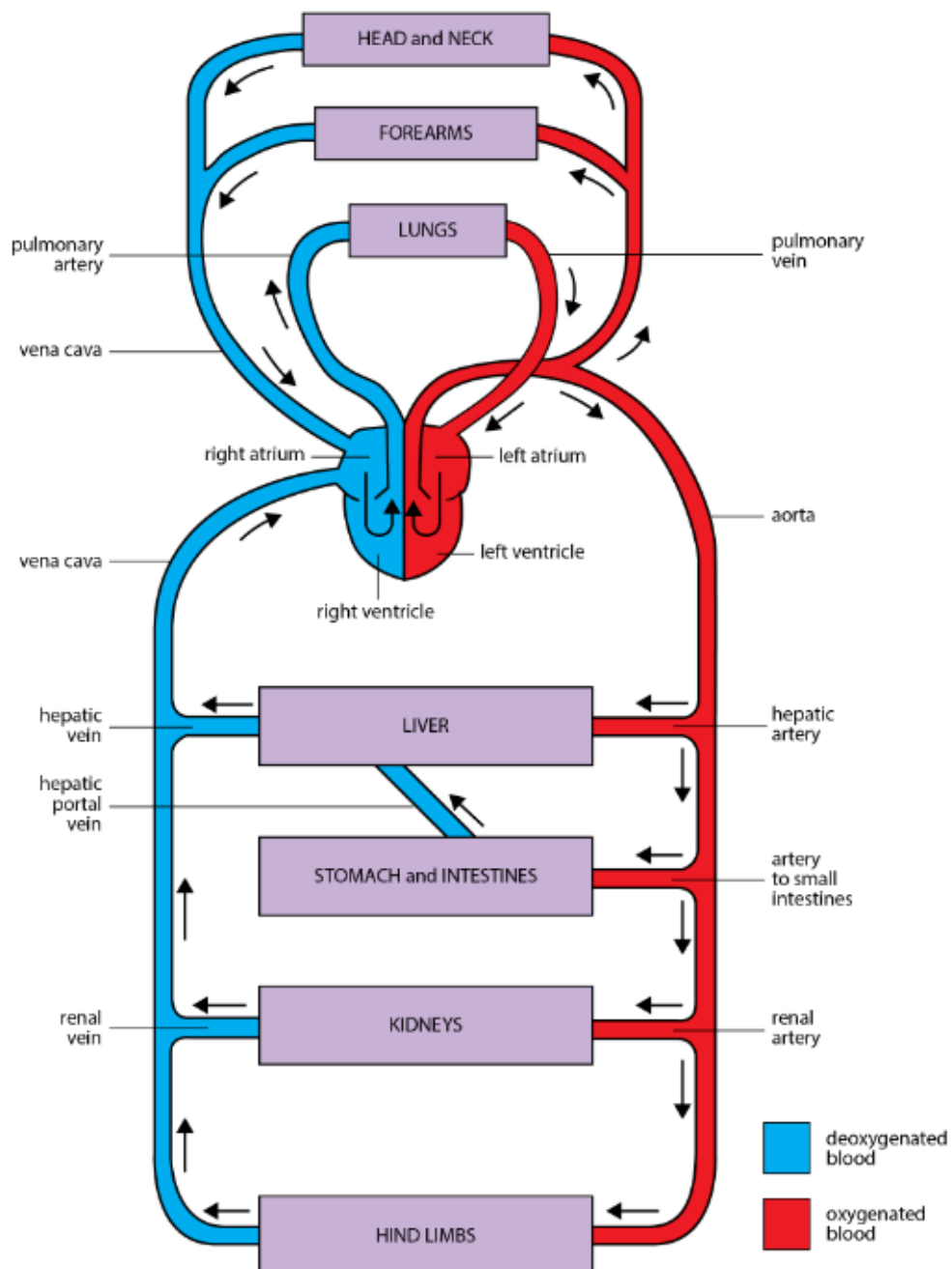


Figure 6.35
Simplified diagram
showing main
arteries and veins
of the human
circulatory system

The Main Veins of the Body

Refer to Figure 6.35 again as you read.

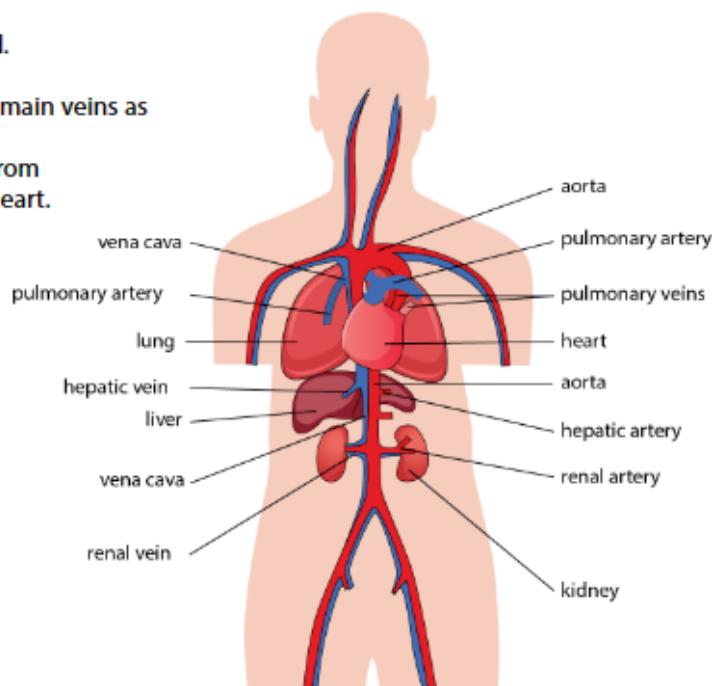
Blood is returned to the heart by the main veins as follows:

- The pulmonary veins bring blood from the lungs to the left atrium of the heart.
- The upper vena cava returns blood from the head, neck and arms to the right atrium.
- The lower vena cava brings blood from the rest of the body to the right atrium.

The lower vena cava receives blood from various veins from the lower parts of the body. Among these are:

- the **renal vein** bringing blood from the kidneys
- the **hepatic vein** bringing blood from the liver

The veins from the small intestine do not open directly into the lower vena cava. Instead, they unite to form the **hepatic portal vein** (Figure 6.35), which enters the liver and branches into numerous capillaries there. A 'portal' vein is so called because it carries blood from one capillary network to another. Thus, the hepatic portal vein arises from capillaries in the wall of the small intestines at one end and gives rise to capillaries in the liver at the other end. Figure 6.36 shows the principal arteries and veins in the human body.



Note that the pulmonary artery carries deoxygenated blood while the pulmonary vein carries oxygenated blood.

■ oxygenated blood
■ deoxygenated blood

Figure 6.36 Human circulatory system showing the principal arteries and veins

Let's Practise 6.4

- 1 State **two** features of the heart which enable it to function efficiently.
- 2 Place the following parts of the circulatory system correctly in the sequence in which blood would flow through them. Take the liver as the starting point.
pulmonary artery, right atrium, hepatic vein, lung, liver, tricuspid valve, right ventricle

Liver →

- 3 A patient has a hole in the wall between the two atria of his heart, as shown in Figure 6.37. As the pressure in the left atrium is higher than in the right atrium, blood flows through the hole mostly from the left to the right. What problems might this cause?

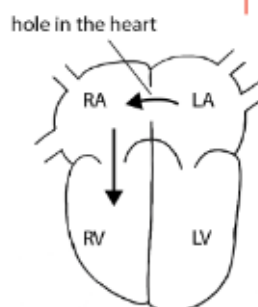


Figure 6.37 A model showing 'hole in the heart' condition



Link

Recall what you have learnt about the function of the hepatic portal vein in Chapter 5.



Link

Theory Workbook
Worksheet 6D

6.5 What Is Coronary Heart Disease?

Learning Outcome

- Describe coronary heart disease in terms of the occlusion of coronary arteries and list the possible causes, such as unhealthy diet, sedentary lifestyle and smoking, stating the possible preventative measures.

You may have seen how a person reacts when he or she suffers a heart attack (Figure 6.38). It can be quite scary and extremely painful. It can happen to old as well as young people. Many people die from a heart attack every day. What is a heart attack, and what can we do to reduce our risk of having one?

The most common heart disease is coronary heart disease. The coronary arteries lie on the outside of the heart, branching from the aorta (Figure 6.39). They carry blood to the muscles in the walls of the heart. Blood supply to the heart muscles can be greatly reduced due to the blockage of the coronary arteries (Figure 6.40). This can cause a **heart attack**.



Figure 6.38 A man experiencing a chest pain, a common sign of a heart attack

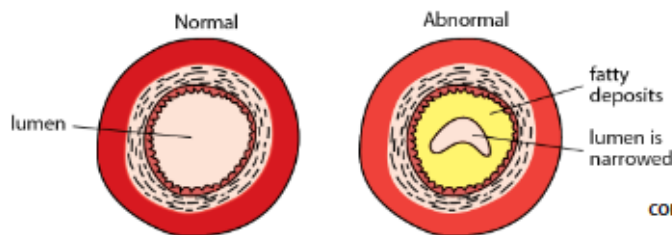


Figure 6.40 Transverse section of two arteries

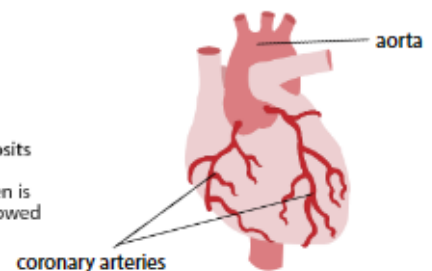


Figure 6.39 Heart showing coronary arteries branching from aorta



Word Alert

Fatal: causing death

What Happens During a Heart Attack?

During a heart attack, blood flow to a particular part of the heart may be completely blocked. Due to the blocked blood flow, that part of the heart does not receive sufficient oxygen and nutrients. That region of the heart muscle dies. Extensive heart muscle damage is often **fatal** as the heart is no longer able to pump blood to the various parts of the body.

What Are the Causes of Coronary Heart Disease?

Fatty substances such as cholesterol and saturated fats may be deposited on the inner surface of the coronary arteries (Figure 6.41). This is called *atherosclerosis*. This narrows the lumen of these arteries and increases blood pressure. Such an affected artery develops a rough inner surface. This increases the risk of a blood clot being formed in the artery. If it occurs in the coronary arteries, the supply of blood and oxygen to the heart muscles may be completely cut off. Oxygen is needed in aerobic respiration to release energy for the activities of the muscle cells. Without oxygen, the heart muscle cells may be damaged, and a heart attack occurs.

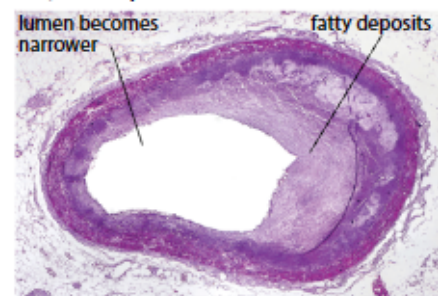


Figure 6.41 Artery with fatty substances deposited in the lumen



Link

You will learn about aerobic respiration in Chapter 7.

What Are the Risk Factors of Heart Disease?

Some risk factors of heart disease are described in Figure 6.42.

Smoking

Cigarette smoke contains carbon monoxide and nicotine which can increase the risk of coronary heart disease. Nicotine increases blood pressure and the risk of blood clotting in the arteries. The risk of smokers developing coronary heart disease is much higher than non-smokers.



Unhealthy diet

A diet high in cholesterol, saturated fats and salt content increases the risk of high blood pressure and heart attack.



Genetic factors

Family history has a role in the risk of developing heart disease. High blood pressure and high blood cholesterol can run in the family.



Age

The risk of a heart attack increases with age. The majority of people suffering from coronary heart disease are 65 or older.



Sedentary lifestyle

Lack of exercise and being inactive lead to the build-up of fatty deposits that block the arteries. This increases the risk of getting coronary heart disease.

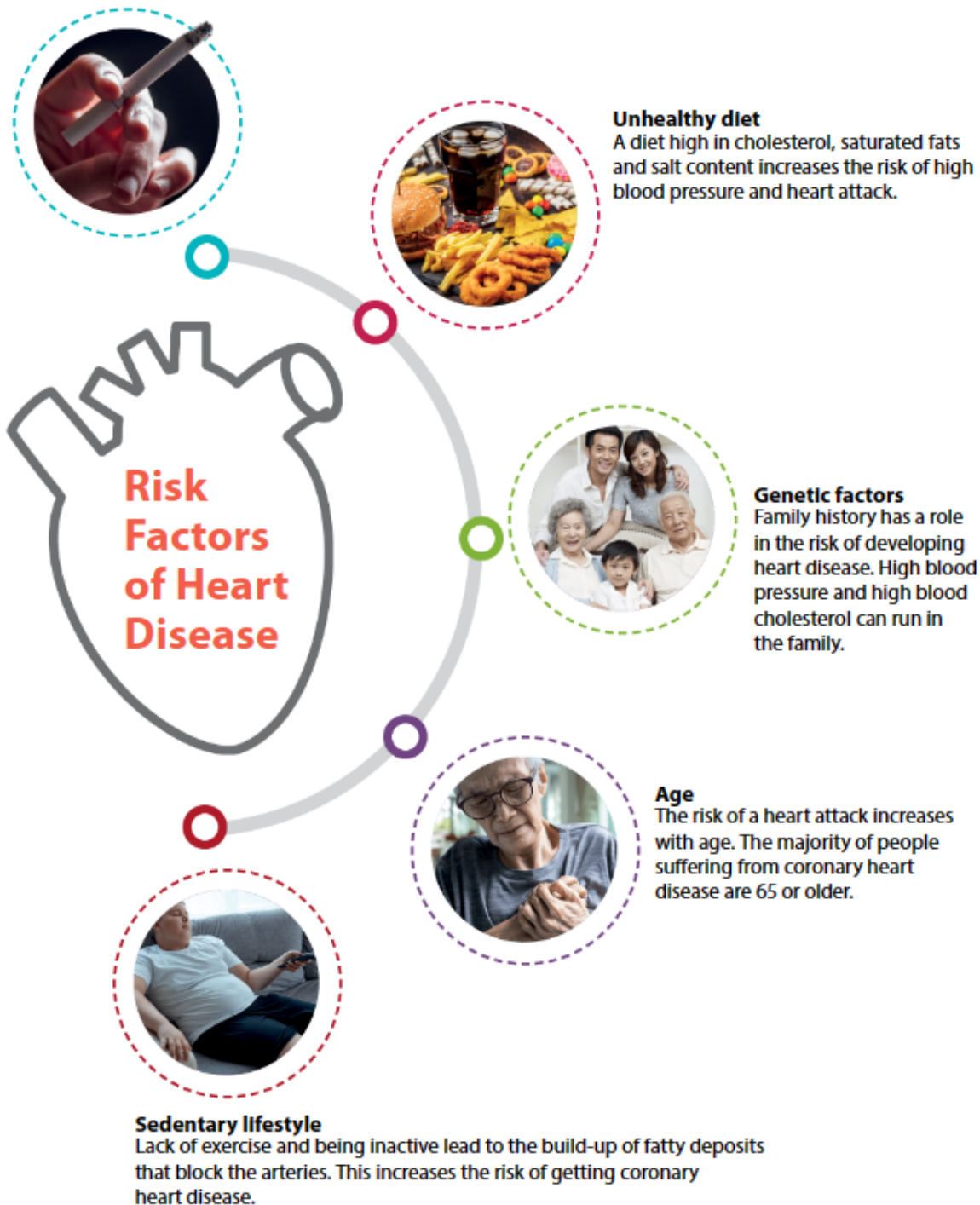


Figure 6.42 Some risk factors of heart disease



Past to Present

Heart disease is not a modern world disease. Evidence of it was found in Egyptian mummies that were more than 3500 years old (Figure 6.43). Right up to the 1920s, there were no suitable treatments, and medicines available then had severe side effects on patients. Today, however heart disease is considered one of the top preventable causes of death in some countries. There is medication to reduce the cholesterol that accumulates and blocks blood vessels. A stent can be inserted to widen the blood vessel and to enable blood to flow more smoothly in the body. These were made possible because scientists, engineers and doctors were curious about the disease which they knew little about. There was also the determination to design solutions that could solve the problem once they understood the causes and effects of the disease.

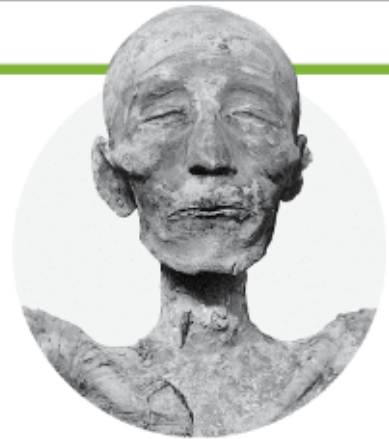


Figure 6.43 Pharaoh Merneptah (died 1203 CE) was found to have heart disease.

What Can We Do to Reduce the Risk of Getting Coronary Heart Disease?

The following are ways to reduce the risk of getting coronary heart disease:

- A healthy diet is important in reducing the risk of atherosclerosis. Animal fats in the diet should be substituted with polyunsaturated plant fats, which do not stick to the inner surface of the arteries. Such a diet may also lower the cholesterol level in the blood.
- Smoking is harmful to the body and should be avoided. Cigarette smoke contains nicotine and carbon monoxide that increase the risk of getting coronary heart disease.
- Regular physical exercise has long-term beneficial effects on the circulatory system. It strengthens the heart and maintains the elasticity of the arterial walls. The risk of high blood pressure or hypertension can be greatly reduced.



Figure 6.44 Ways to reduce the risk of getting coronary heart disease



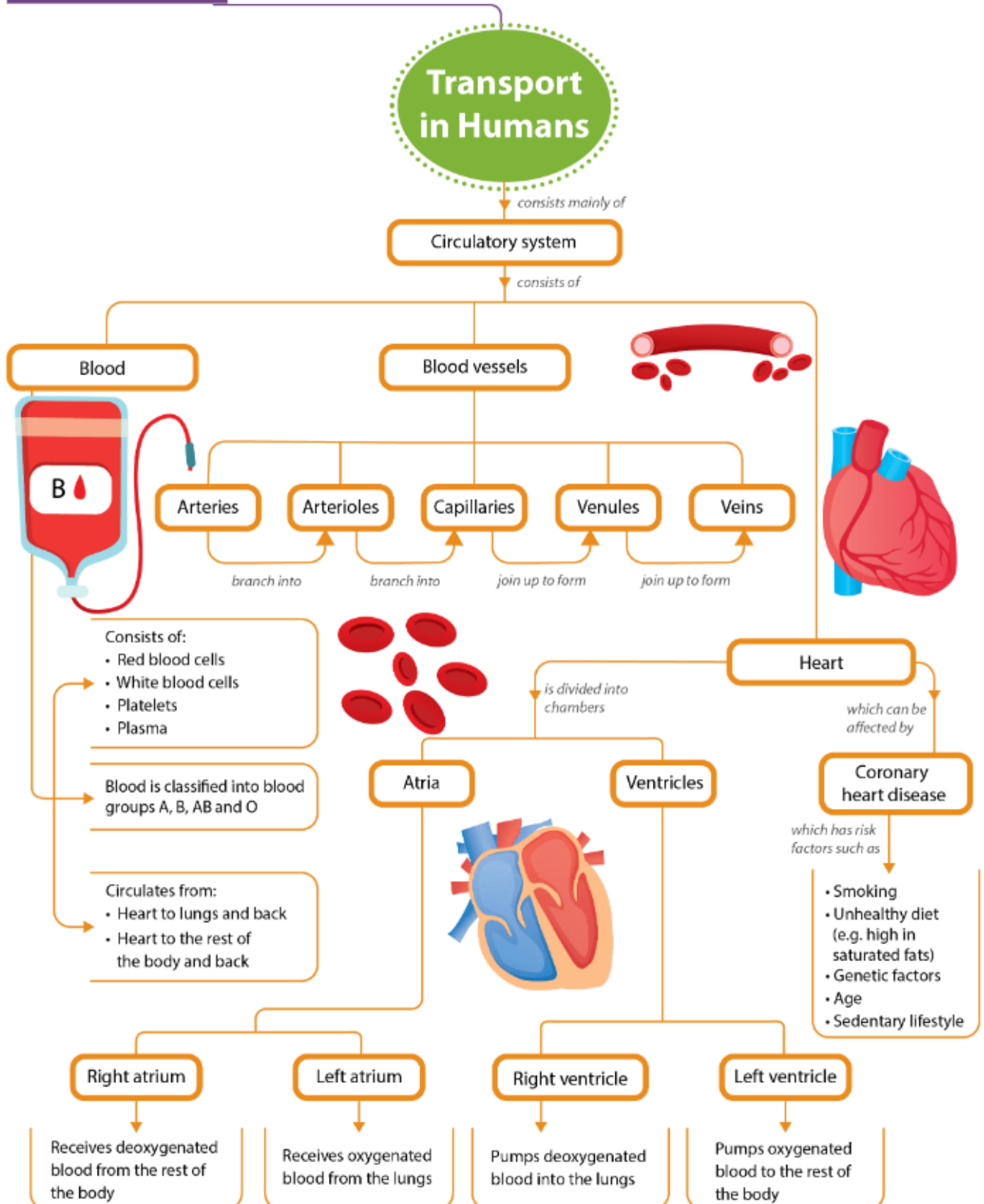
Link

Theory Workbook
Worksheet 6E
Let's Assess
Let's Reflect

Let's Practise 6.5

- 1 How does a diet high in saturated fat increase the risk of getting coronary heart disease?
- 2 Name **two** other risk factors of heart disease.

Let's Map It



Let's Review

Section A: Multiple-choice Questions

Examine Figure 6.45 and answer questions 1–3.

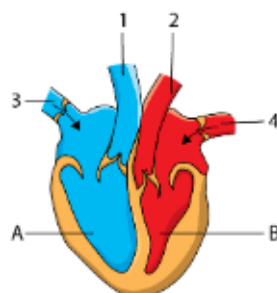


Figure 6.45

- Which blood vessels carry oxygenated blood?
☐ A 1 and 2 ☐ B 2 and 3
☐ C 2 and 4 ☐ D 3 and 4
- Which of the blood vessels supplies oxygenated blood to the heart muscles?
☐ A 1 ☐ B 2
☐ C 3 ☐ D 4
- Which of the following is **not** involved in bringing blood from A to B?
☐ A 1 and 2 ☐ B 2 and 4
☐ C 2 and 3 ☐ D 3 and 4

Figure 6.46 shows the pressure changes in the left side of the heart. With reference to the graph, answer questions 4–5.

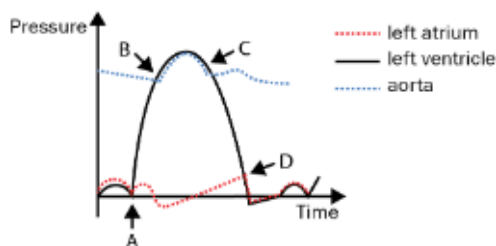


Figure 6.46

- At which point does the bicuspid valve begin to close?
- At which point does the bicuspid valve begin to open?

Section B: Structured Questions

- Figure 6.47 shows some tissue cells and a blood vessel.

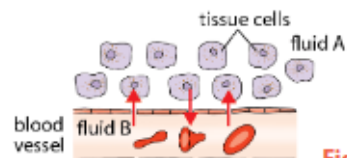


Figure 6.47

- Name the fluid A and B.
 - Name **one** chemical substance that passes from fluid:
 (i) A to B (ii) B to A
 - What type of blood vessel is shown in the diagram? Give **two** reasons to support your answer.
- The blood of three people, X, Y and Z, was tested with plasma from blood of different groups to determine their blood groups. Table 6.3 shows the test results.

Table 6.3

Blood of Person	X	Y	Z
Plasma from Blood of Group A	clumps	clumps	no clumping
Plasma from Blood of Group B	no clumping	clumps	no clumping

- To which blood group does each person belong?
- What causes the red blood cells of person X to clump together when his blood is mixed with plasma from group A?
- What blood group(s) must a donor belong to if he is to donate blood to person Z?
- A donor has blood group A. To which blood groups can his blood be given safely?

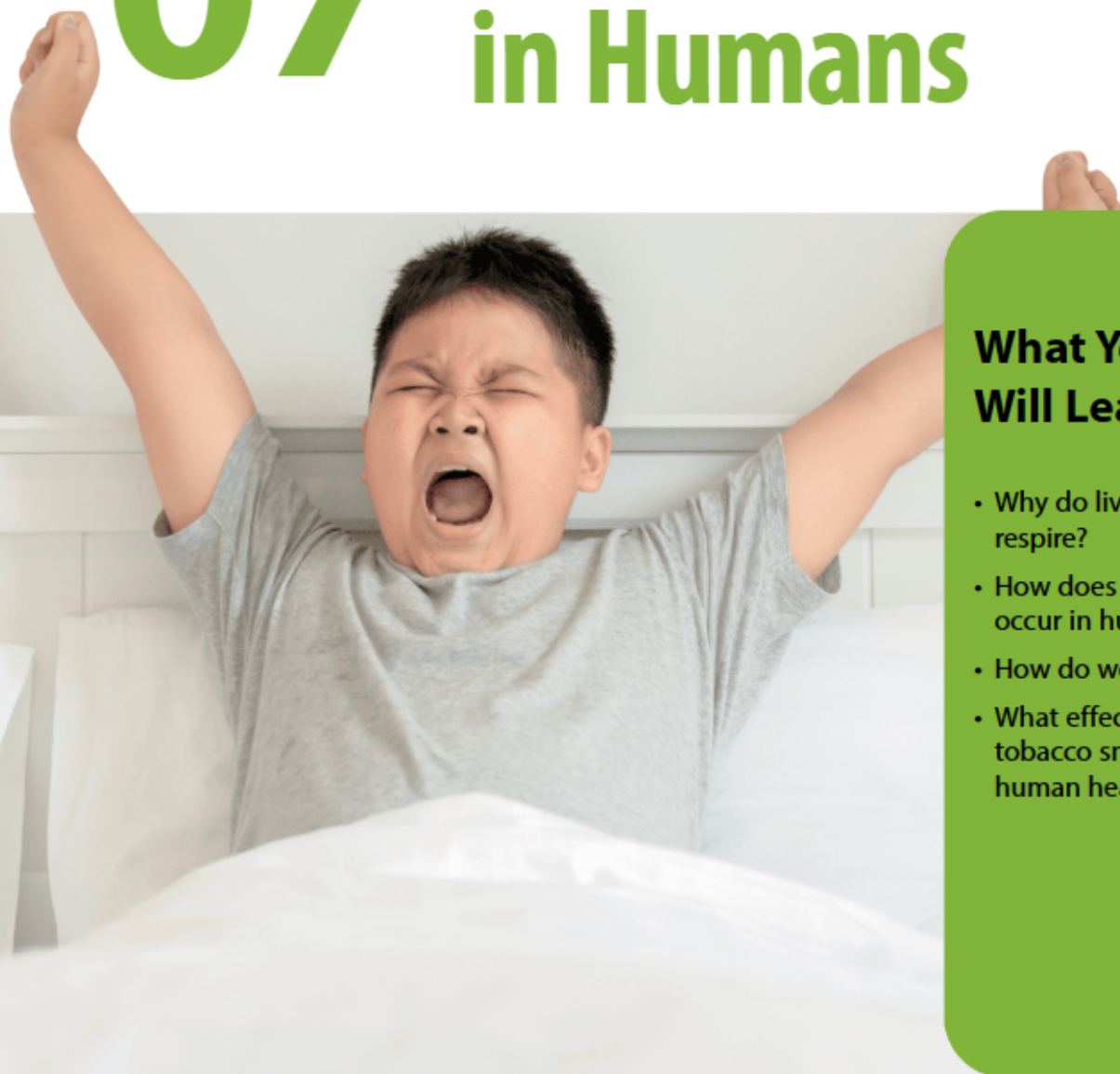
Section C: Free-response Questions

- The number of white blood cells increases in a patient's bloodstream shortly after surgery. Suggest and explain **one** possible cause of this increase.
- Describe the cardiac cycle in terms of what happens during systole and diastole.

CHAPTER

07

Respiration in Humans



What You Will Learn



- Why do living things respire?
- How does gas exchange occur in humans?
- How do we breathe?
- What effects does tobacco smoke have on human health?

Why do we yawn? Do we yawn more when we are exercising or when we are resting? What do you think happens when we yawn? Will increasing the level of oxygen in the surrounding air make us yawn less?



7.1 Why Do Living Things Respire?

Learning Outcomes

- Define *aerobic respiration* in human cells as the release of energy by the breakdown of glucose in the presence of oxygen and state the equation, in words and symbols.
- Define *anaerobic respiration* in human cells as the release of energy by the breakdown of glucose in the absence of oxygen and state the word equation.
- Explain why cells respire anaerobically during vigorous exercise resulting in an oxygen debt that is removed by rapid, deep breathing after exercise.



Disciplinary Idea

Energy

Living organisms rely on respiration to release energy from the breakdown of carbohydrates. Energy is needed to carry out processes to sustain life.

When we are hungry, we can become weak and unable to function properly. We need food to give us energy. Our bodies digest the food and break it down into simpler substances which are used for various functions, including releasing energy. What happens to the glucose in our cells during energy release?

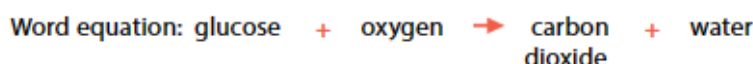
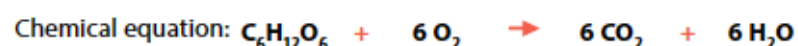
Living organisms need energy to move, excrete, grow and reproduce. Since energy is stored in food molecules such as glucose, living organisms release energy by consuming these molecules and breaking them down through a process known as *respiration*.

There are two forms of respiration: **aerobic** and **anaerobic** respiration.

What Is Aerobic Respiration?

- ▶ **Aerobic respiration** is the release of energy by the breakdown of glucose in the presence of oxygen. Carbon dioxide and water are released as waste products. Aerobic respiration releases a large amount of energy.

The overall equation for aerobic respiration of glucose is:



This process releases a large amount of energy.

The process is more complicated than the equation shown above. In reality, respiration is carried out in a series of steps that are catalysed by enzymes. The mitochondria in cells are the 'factories' that contain these enzymes. Thus, mitochondria play a vital role in aerobic respiration.

Complex organisms, such as trees and humans, respire aerobically as they need large amounts of energy to survive. Some examples of energy-consuming processes in organisms are:

- synthesis of new protoplasm for growth and repair
- synthesis of proteins from amino acids
- active transport in the absorption of food substances by the small intestine
- muscular contractions such as heartbeats and respiratory movements
- transmission of nerve impulses
- cell division



Link

Chemistry

Aerobic respiration occurs in the presence of oxygen. It is an oxidation process, which is a chemical reaction in which a molecule gains oxygen or loses hydrogen.



Link

Mitochondria are one of the many organelles inside our cells. Recall what you have learnt in Chapter 1.

During respiration, some energy is also released as heat. This heat is circulated around your body by the blood to keep you warm.



What Is Anaerobic Respiration?

- ▶ **Anaerobic respiration** is the release of energy by the breakdown of glucose in the absence of oxygen. Anaerobic respiration releases a relatively small amount of energy.

In Muscle Cells

During vigorous muscular contractions, your muscle cells respire aerobically at a high rate. You may start panting in order to remove carbon dioxide and take in oxygen at a faster rate. Your heart will also begin to beat faster so that the oxygen can be transported to your muscles at a faster rate. However, there is a limit to the increase in the rate of breathing and heartbeat.

When vigorous activity continues, muscular contractions are so vigorous that maximum aerobic respiration is unable to release energy fast enough to meet the demand. If vigorous muscular contractions continue, energy demand increases. The muscle cells carry out anaerobic respiration to meet the increased energy demand. **Lactic acid** is formed in the process.

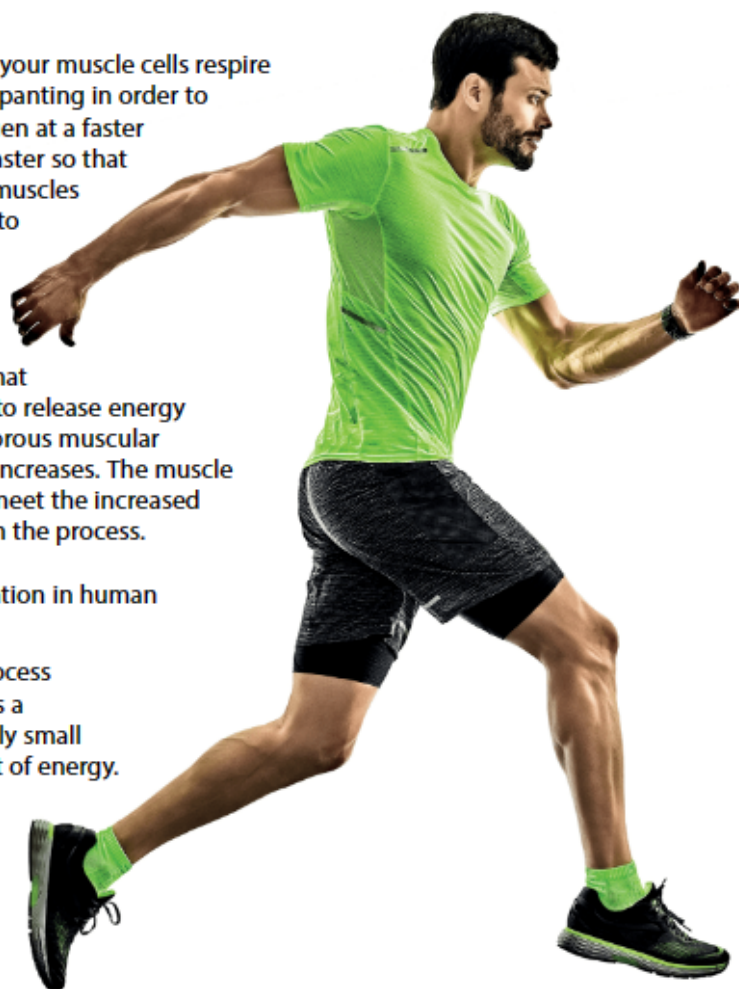
The word equation for anaerobic respiration in human muscles is:

glucose → lactic acid

This process releases a relatively small amount of energy.

The small amount of energy released in anaerobic respiration, together with the energy released in aerobic respiration, helps the muscles to keep contracting. Since there is insufficient oxygen to meet the demands of the vigorous muscular contractions, the muscles are said to incur an **oxygen debt**.

- ▶ **Oxygen debt** is the amount of oxygen required to remove lactic acid.



How Can Oxygen Debt (or Lactic Acid) Be Removed After a Race?

1 Continuation of fast heart rate

This results in continued and fast transport of:

- lactic acid from the muscles to the liver
- oxygen from the lungs to the liver

2 Continuation of deeper and faster breathing

This results in continued and fast intake of oxygen by the lungs. Sufficient oxygen is required to remove the lactic acid from the blood. Once the lactic acid is removed, the oxygen debt is repaid.

Note that during a sprint event or a short distance race, the athlete obtains some of his or her energy from anaerobic respiration. This is because a lot of energy is needed during a short period of time. The oxygen supply to the muscles is insufficient for aerobic respiration to meet the energy demand.

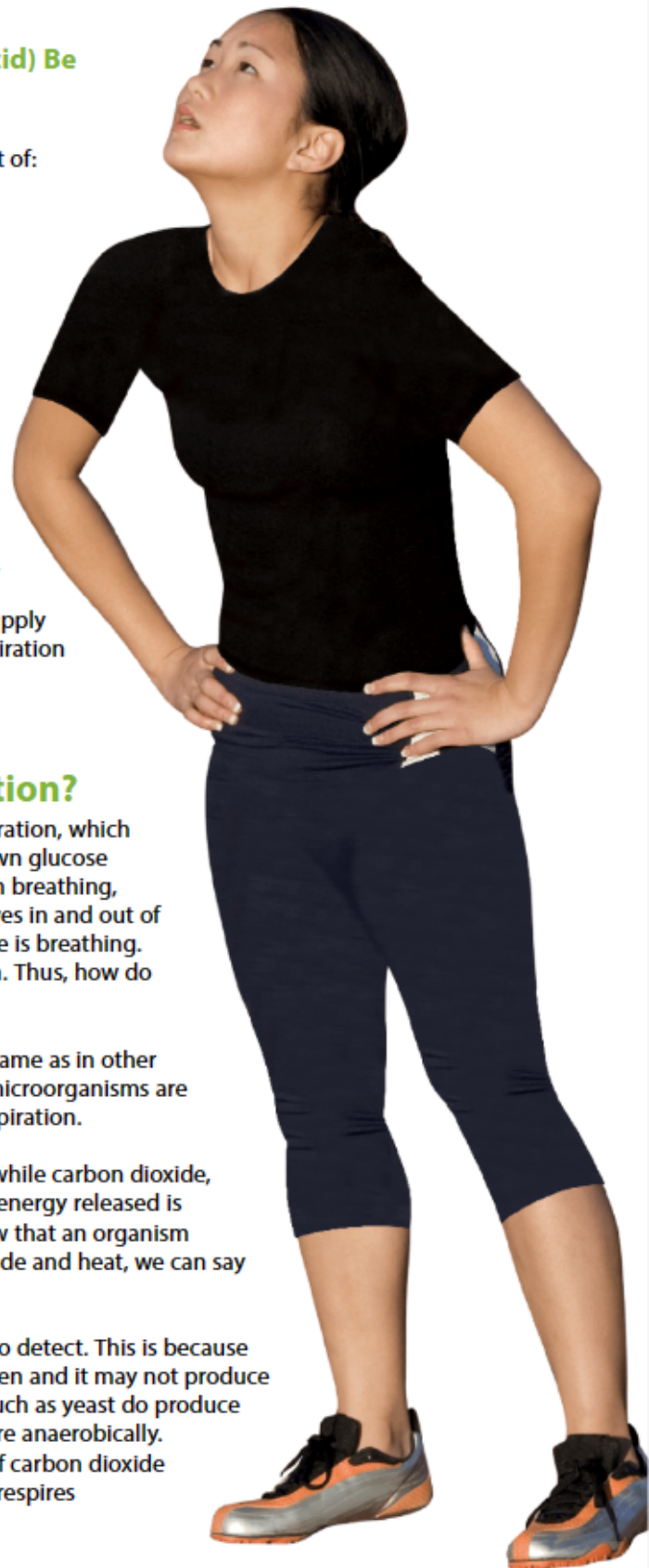
How Do We Study Respiration?

Respiration in biology refers to cellular respiration, which is the release of energy when cells break down glucose in the presence of oxygen. It is different from breathing, which refers to the process by which air moves in and out of the lungs. It is quite easy to check if someone is breathing. However, it is harder to check for respiration. Thus, how do we study respiration?

The process of respiration in humans is the same as in other organisms. Thus, plants, small animals and microorganisms are often used in experiments to investigate respiration.

In aerobic respiration, oxygen is consumed while carbon dioxide, energy and water are released. Some of the energy released is in the form of heat. Therefore, if we can show that an organism consumes oxygen and gives off carbon dioxide and heat, we can say that it respire aerobically.

Anaerobic respiration in humans is difficult to detect. This is because it does not require the consumption of oxygen and it may not produce carbon dioxide. However, microorganisms such as yeast do produce and give off carbon dioxide when they respire anaerobically. Therefore, if we can show that yeast gives off carbon dioxide in the absence of oxygen, we can say that it respire anaerobically.



Let's Investigate 7.1**Aim**

To find out if carbon dioxide is given off during aerobic respiration

Procedure (a)

- 1 Set up the apparatus as shown in Figure 7.1. Potassium hydroxide solution is used to absorb carbon dioxide. Sodium hydroxide can also be used for this. Limewater is used to test the presence of carbon dioxide, which turns the limewater cloudy.
- 2 Use a suction pump to suck out the air through delivery tube E. This causes air to be drawn into flask A. The air flows through the apparatus as shown by the arrows.

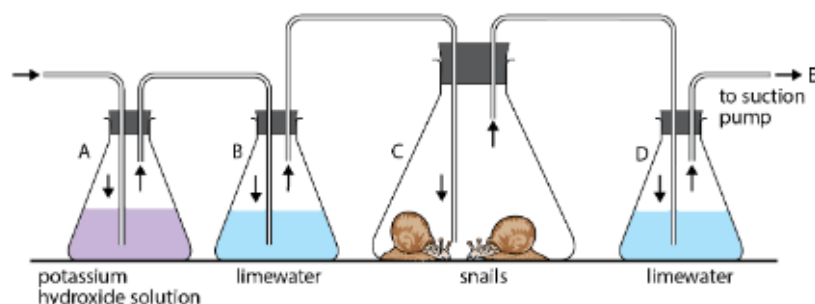


Figure 7.1

Questions

- 1 What purpose does the potassium hydroxide solution in flask A and limewater in flask B serve?
- 2 What happens to the limewater in flask D after some time? Explain your observation.
- 3 You need to set up a control. What changes would you make to flask C for the control?
- 4 If your investigation uses a potted green plant, what precautions must you take? Explain your answer.

Procedure (b)

Alternatively, we can use a hydrogencarbonate indicator, which can detect changes in carbon dioxide concentration. The colour changes in the indicator are shown in Figure 7.2.

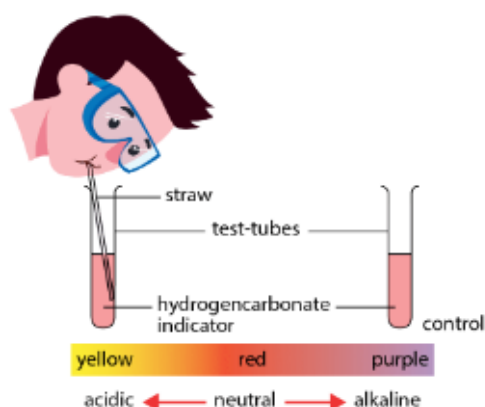


Figure 7.2

- 1 Set up the apparatus as shown in Figure 7.2.
- 2 Gently blow through the straw several times for 1 min.

Question

- 1 What changes do you see in the two tubes after 1 min? Why?

**Helpful Note**

At the surface of a liquid, molecules are constantly escaping from the liquid as gas. Some may return to the liquid. As the suction pump sucks out the air from flask D, it reduces the air pressure above the liquid surface. This leads to more gas molecules escaping from the liquid in flask D.

As air is continuously sucked out from flask D, a pressure difference is created between the flasks, allowing air to flow in the direction as shown by the arrows.

To study anaerobic respiration, yeast is used as a model organism.

Let's Investigate 7.2

Aim

To find out if carbon dioxide is given off during fermentation (anaerobic respiration)

Procedure

- 1 Add a few grains of dry yeast to some distilled water in a boiling tube. Stir well.
- 2 After 20 minutes, add an equal volume of boiled and cooled dilute glucose solution to the yeast suspension and mix well.
- 3 Add a little oil.
- 4 Connect the boiling tube to a test-tube containing limewater as shown in Figure 7.3.

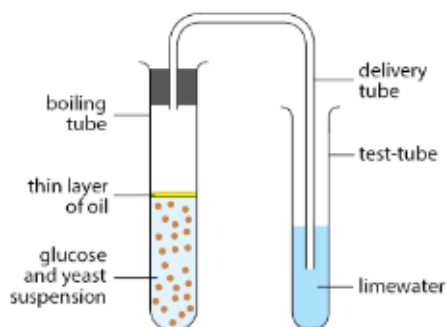


Figure 7.3

Questions

- 1 Why do you need to boil the glucose solution before carrying out the experiment?
- 2 What does the layer of oil serve as?
- 3 What do you observe after some time? Explain your answer.
- 4 What would you add to the boiling tube in a control experiment?



Link

Practical Workbook
Experiment 7A



Helpful Note

Yeast (Figure 7.4) is a microorganism that respire aerobically in the presence of oxygen, but respire anaerobically in the absence of oxygen.

In fermentation, yeast releases ethanol (a type of alcohol) and carbon dioxide as waste products during anaerobic respiration. The ethanol produced still contains energy and this explains why only a small amount of energy is released in anaerobic respiration.

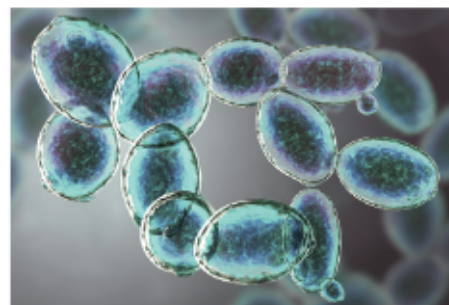
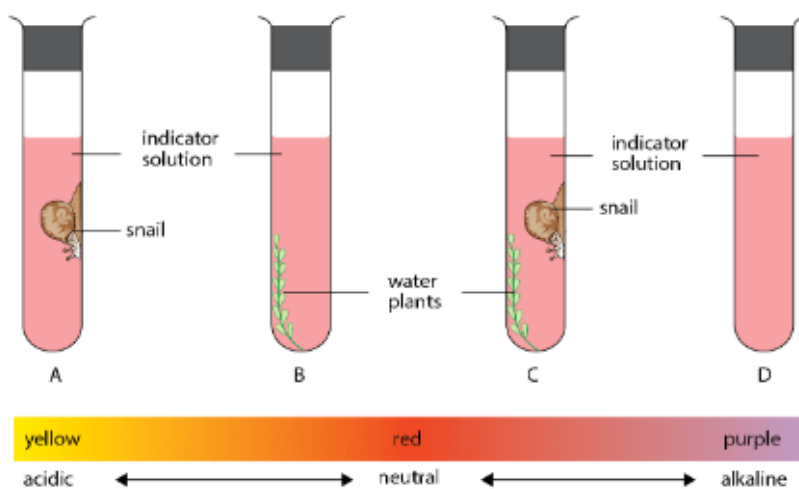


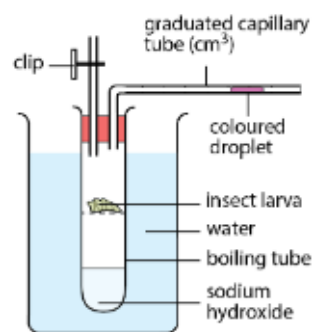
Figure 7.4 Yeast cells

Let's Practise 7.1

- 1 Why is respiration important to humans?
- 2 (a) Write the equations, in words and symbols, for aerobic respiration in humans.
(b) Write the word equation for anaerobic respiration in human muscle cells.
- 3 Suggest **two** reasons why we need energy when we sleep.
- 4 Four test-tubes are set up as shown in Figure 7.5. All the tubes contain the same amount of neutral indicator (red) and are left in sunlight for one hour.

**Figure 7.5**

- (a) What colour change would you expect to occur in tube A and tube B? Why?
- (b) If the colour of the indicator in tube C does not change, what explanation can you give?
- (c) Would you expect the indicator in tube D to change colour? Why?
- 5 Figure 7.6 shows the apparatus used to investigate respiration.
 - (a) What can be measured using the apparatus shown?
 - (b) What is the purpose of the sodium hydroxide solution?
 - (c) In which direction will the coloured droplet move as the insect respires?
 - (d) Explain your answer in (c).

**Figure 7.6****Link****Theory Workbook**
Worksheets 7A–7B

7.2 How Does Gas Exchange Occur in Humans?

Learning Outcomes

- Identify the larynx, trachea, bronchi, bronchioles, alveoli and associated capillaries and state their functions in human gaseous exchange.
- Explain how the structure of an alveolus is related to its function of gaseous exchange, including describing the role of the cilia.

Breathing and life are intimately connected. In many languages, the same word is used for 'breath' and 'spirit'. We usually check for breathing to determine if someone is still alive. If you try to hold your breath, after a certain time, your body fights to breathe again. Your body is programmed to keep breathing. Why is breathing so important?

How Do Organisms Take In Oxygen for Aerobic Respiration?

Organisms take in oxygen for aerobic respiration through the process of **gas exchange**.

- ▶ **Gas exchange** is the exchange of gases between an organism and the environment.

Unicellular organisms, such as amoebae, have a large surface area-to-volume ratio. Such organisms do not require any special gas exchange system or oxygen transport mechanisms. Oxygen and carbon dioxide can be exchanged efficiently between the organism and the surrounding water by diffusion through the cell membrane.

Large animals, such as fish, amphibians and mammals, have a comparatively smaller surface area-to-volume ratio. Their external surfaces are often thickened for protection and to prevent water loss. Therefore, these surfaces are not suitable for gas exchange. These animals use special organs, such as lungs and gills, for gas exchange. These organs have enlarged surface areas and thin coverings. In this way, more oxygen can be absorbed and more carbon dioxide removed from the body per unit time.

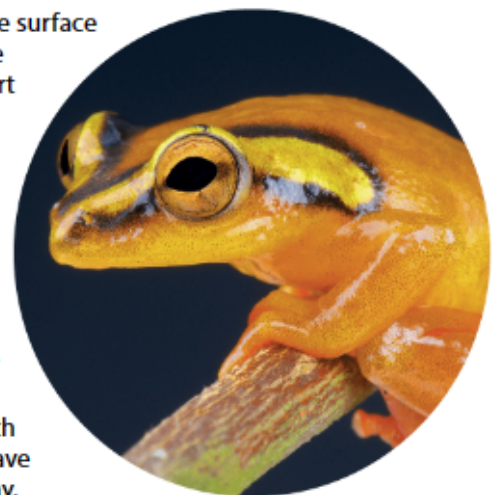


Figure 7.7 Frogs have lungs and permeable skin for gas exchange.

In humans, the absorption of atmospheric oxygen and the removal of carbon dioxide from the body occur in the alveoli (air sacs) in the lungs.

The Human Gas Exchange System

The organs involved in gas exchange in humans are shown in Figure 7.8 on the next page. They include the two **lungs** in the thorax and the air passages leading to them. The air passages consist of the **nasal passages, pharynx, larynx, trachea, bronchi** and **bronchioles**. The **thoracic cavity, ribs, diaphragm** and related muscles are also vital parts of the gas exchange system, and their functions will be discussed in Section 7.3, which covers the breathing mechanism in humans.



Link

How does a large surface area-to-volume ratio aid diffusion? Recall what you have learnt in Chapter 2.



Word Alert

Permeable: porous

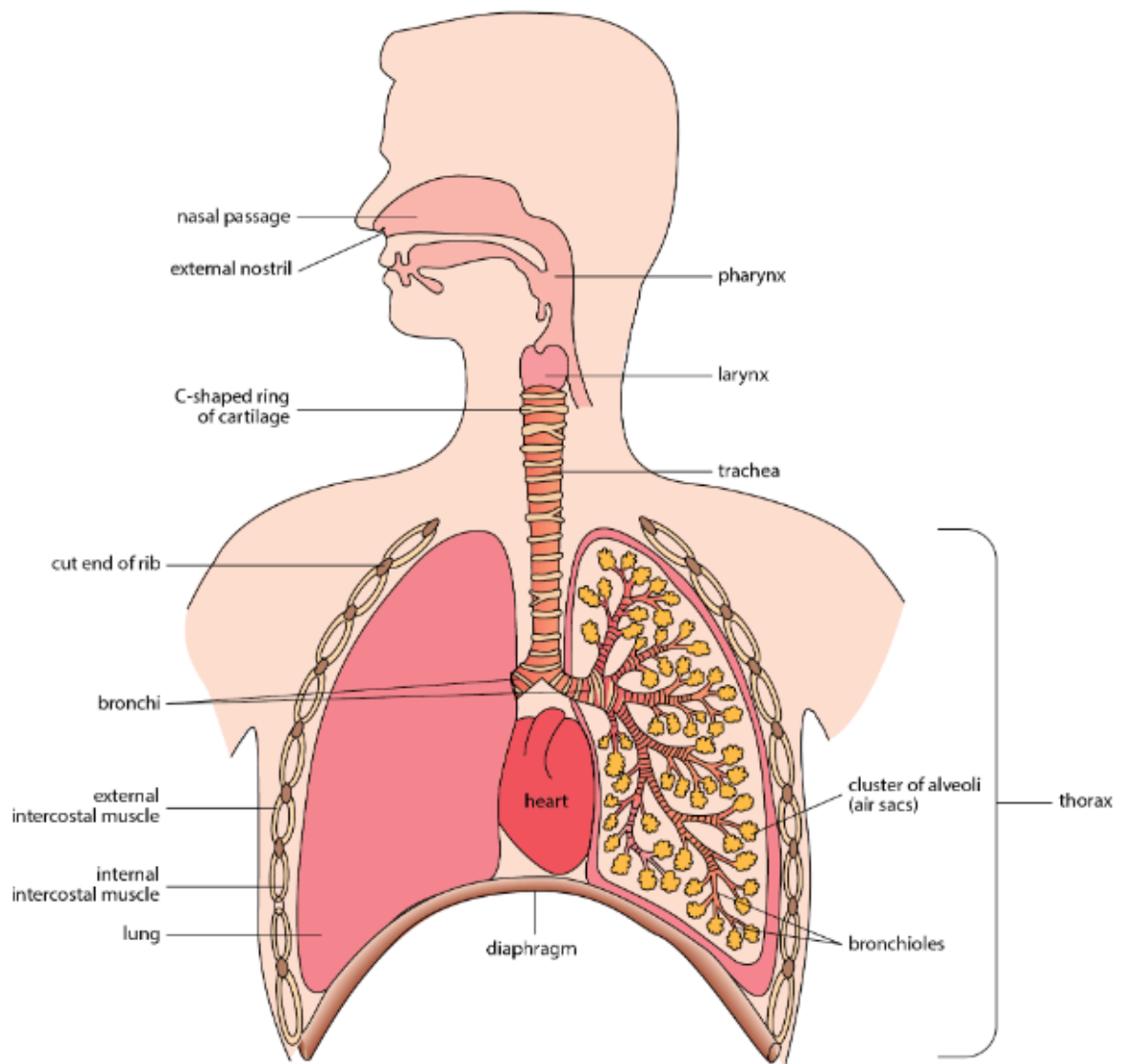


Figure 7.8 The human gas exchange system

The Nose

Air usually enters your body through the two **external nostrils**. The walls of the nostrils bear a fringe of hairs. The nostrils lead into two nasal passages, which are lined with a moist mucous membrane. Breathing through the nose has the following advantages:

- Dust and foreign particles, including bacteria in the air, are trapped by the hairs in the nostrils as well as by the mucus on the mucous membrane.
- As air passes through the nasal passages, it is warmed and moistened.
- Harmful chemicals may be detected by small sensory cells in the mucous membrane.

From the Nose to the Trachea

The air in your nasal passages enters the **pharynx**. From the pharynx, air passes into your **larynx** and then into your trachea through an opening.



Disciplinary Idea

System

The respiratory system comprises various organs that facilitate gaseous exchange.

Trachea

The trachea (windpipe) is supported by C-shaped rings of cartilage (Figure 7.9). The cartilage keeps the lumen of the trachea open.

The membrane next to the lumen is the epithelium. The epithelium consists of two types of cells.

- **Gland cells** — secrete mucus to trap dust particles and bacteria
- **Ciliated cells** — have hair-like structures called **cilia** on their surfaces. The cilia sweep the dust-trapped mucus up the trachea.

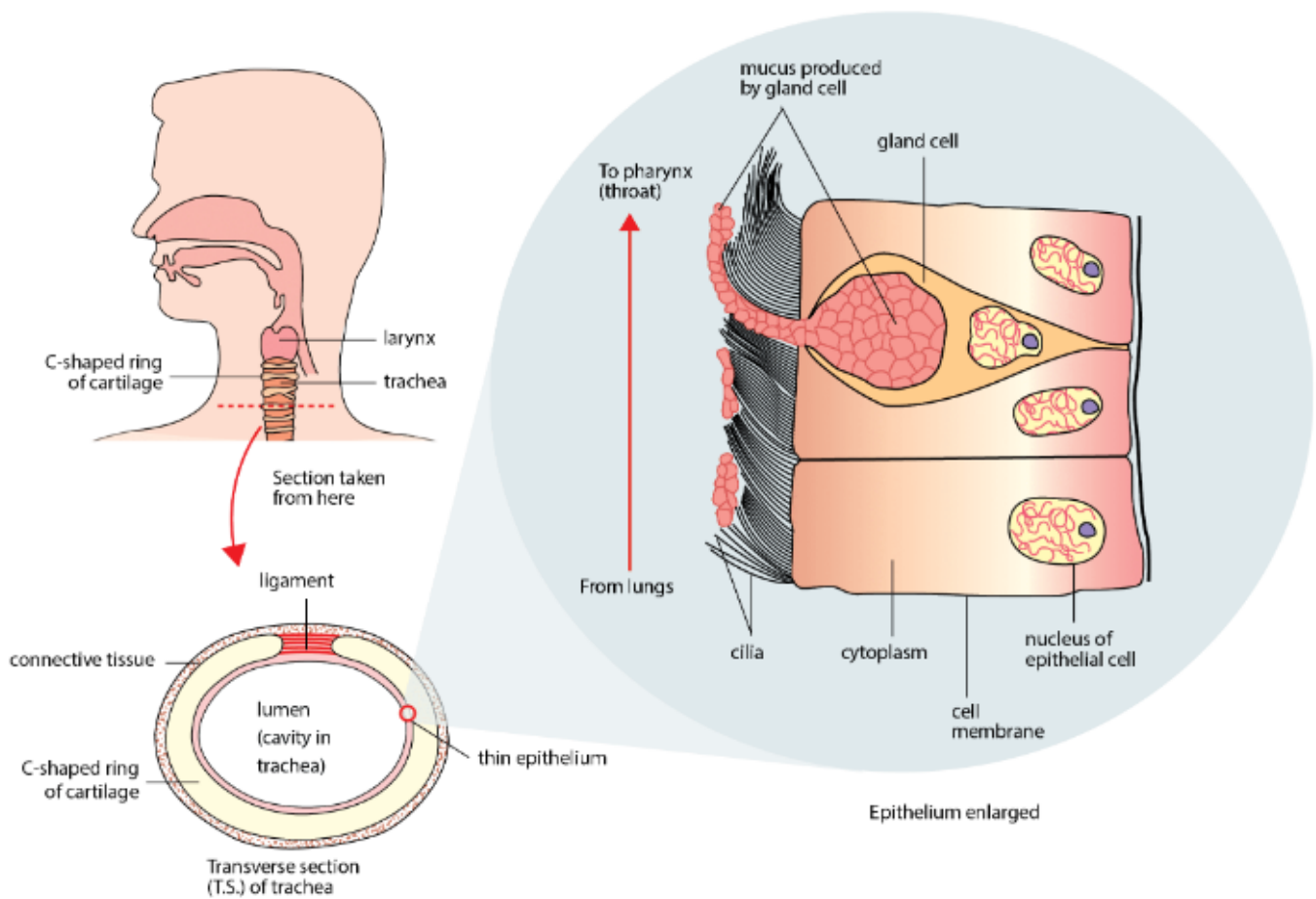


Figure 7.9 Features of the air passages

Bronchi and Bronchioles

The trachea divides into two tubes called **bronchi** (singular: **bronchus**). Each bronchus carries air into the lung. The bronchi are similar in structure to the trachea. Each bronchus branches repeatedly, giving rise to numerous **bronchioles**. Bronchioles are very fine tubes. Each bronchiole ends in a cluster of **air sacs** or **alveoli**.

Alveoli (Air Sacs)

Gas exchange takes place through the walls of the alveoli (Figure 7.10). Numerous alveoli are found in the lungs, providing a very large surface area for gas exchange.

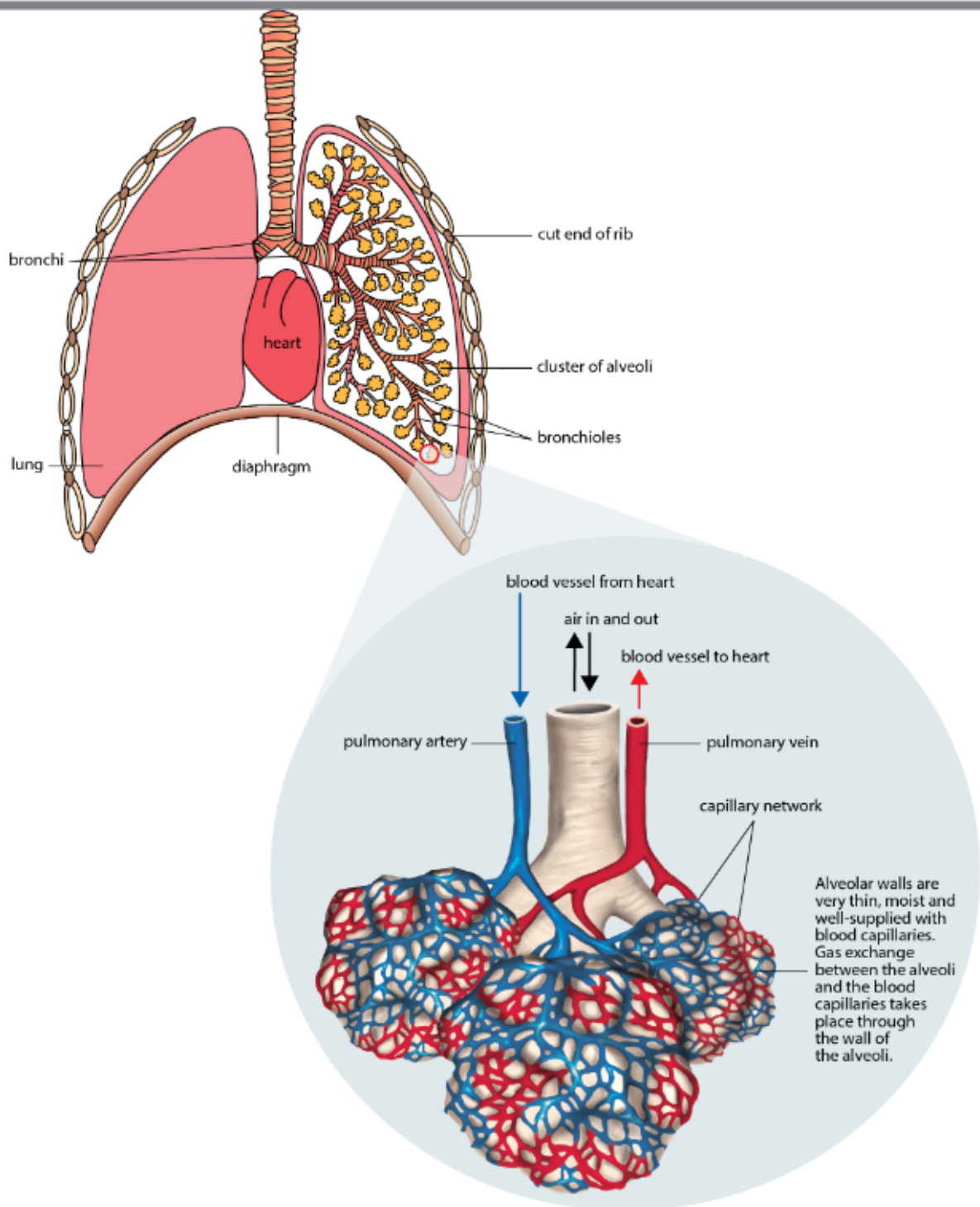


Figure 7.10 The lungs showing a cluster of alveoli and its associated capillaries

How Are the Lungs Adapted for Efficient Gas Exchange?

- The numerous alveoli in the lungs provide a large surface area.
- The wall of the **alveolus** is only one cell thick. This provides a short diffusion distance for gases, ensuring a higher rate of diffusion.
- A thin film of moisture covers the inner wall of the alveolus. This allows oxygen to dissolve in it.
- The walls of the alveoli are richly supplied with blood capillaries. The flow of blood maintains the concentration gradient of gases.



Word Alert

Alveolus: singular of alveoli



Link

Diffusion requires a concentration gradient. Recall what you have learnt in Chapter 2.



Disciplinary Idea

Structure and Function

The structure of the alveoli is designed to allow efficient gas exchange in humans.



How Does Gas Exchange Occur in the Alveoli?

Gas exchange in the lungs occurs by diffusion. Blood entering the lungs has a lower concentration of oxygen and a higher concentration of carbon dioxide than the atmospheric air entering the alveoli in the lungs. A concentration gradient for oxygen and carbon dioxide is set up between blood and alveolar air (Figure 7.11).

- Oxygen dissolves into the thin film of moisture on the wall of the alveolus.
- The dissolved oxygen then diffuses through the wall of the alveolus and the wall of the blood capillary into the red blood cells.
- The oxygen combines with haemoglobin to form oxyhaemoglobin.
- Carbon dioxide diffuses from the blood into the alveolar air.

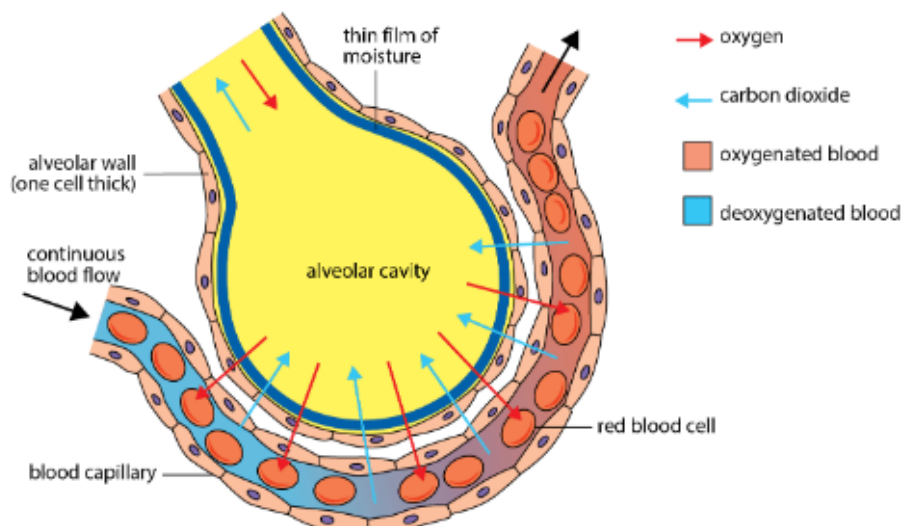


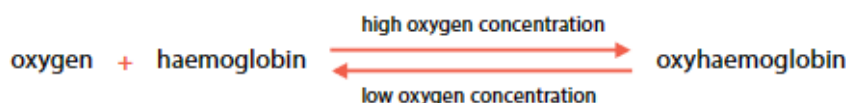
Figure 7.11 A section of an alveolus

The oxygen and carbon dioxide concentration gradients between the alveolar air and the blood are maintained by:

- a continuous flow of blood through the blood capillaries
- continuous breathing, which causes air in the lungs to be constantly refreshed

How Is Oxygen Transported Around the Body?

In the lungs where the oxygen concentration is high, oxygen combines with haemoglobin in the red blood cells to form oxyhaemoglobin. Oxygenated blood is transported from the lungs to other parts of the body.



When blood passes through an organ or tissue where the oxygen concentration is low, oxyhaemoglobin will release its oxygen to the respiring cells.

How will oxygen transport in a person's body be affected if he holds his breath for a long time? Comment on the views given by the three people in Figure 7.12. Explain why each of them is correct or incorrect.

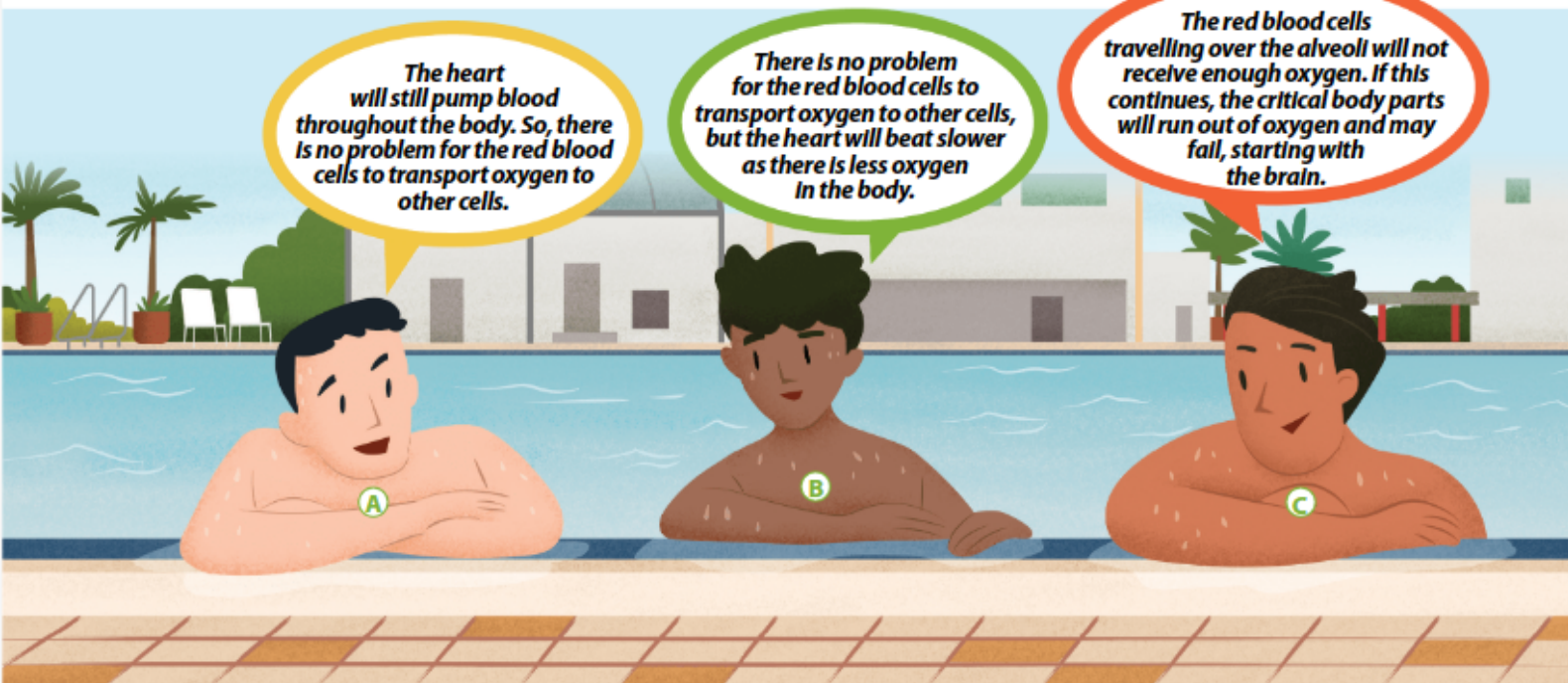


Figure 7.12 Three people are discussing the effect on oxygen transport in the body if a person holds his breath for a long time. Comment on their views.

Let's Practise 7.2

- 1 Name the parts labelled A to G in Figure 7.13.
- 2 Figure 7.14 shows some cells from the lining of a human trachea.
 - (a) Name the parts labelled A, B and C.
 - (b) The diagram is incomplete. Complete it by drawing the cilia that should be found on the cells. Your drawing should show the direction in which the cilia are sweeping.
 - (c) What is the name of the substance that the gland cells secrete?
 - (d) Based on your understanding of the function of the cilia, what would happen if they were paralysed?



Link

Theory Workbook
Worksheet 7C

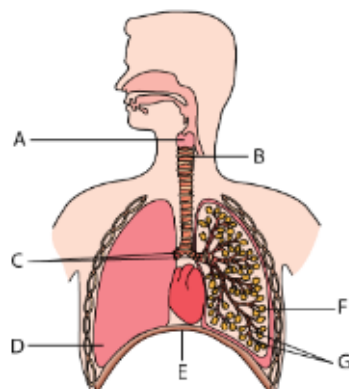


Figure 7.13

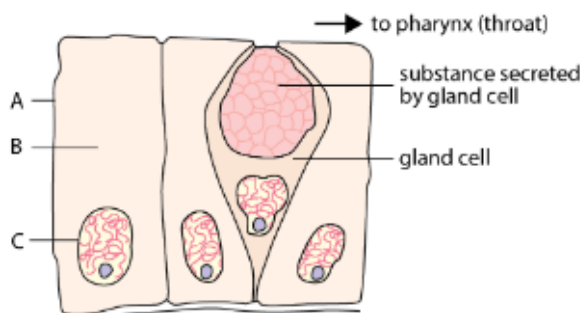


Figure 7.14 Cells lining the human trachea

7.3 How Do We Breathe?

Learning Outcome

- Describe the process of breathing and the role of diaphragm, ribs and internal and external intercostal muscles.

Have you ever seen opera singers sing a very long note without pausing for breath? Do you wonder how they can take in so much air and control the breath? It is all due to the highly trained muscles of their breathing mechanism. Yes, breathing is an activity that involves muscles, and it can be trained.

Breathing is part of the gas exchange process. It refers to the muscular contractions and movements of the ribs, which result in air moving in and out of the lungs. Humans possess special breathing mechanisms that increase the rate of gas exchange between the body and the external environment. The breathing movements essentially consist of two phases:

- The taking in of air called **inhalation** or **inspiration**.
- The giving out of air called **exhalation** or **expiration**.

The Thoracic (Chest) Cavity

The chest wall is supported by the ribs. Between the ribs, two sets of muscles, the **external** and **internal intercostal muscles**, can be found (Figure 7.15). They are antagonistic muscles. This means that when the external intercostal muscles contract, the internal intercostal muscles relax, and vice versa.

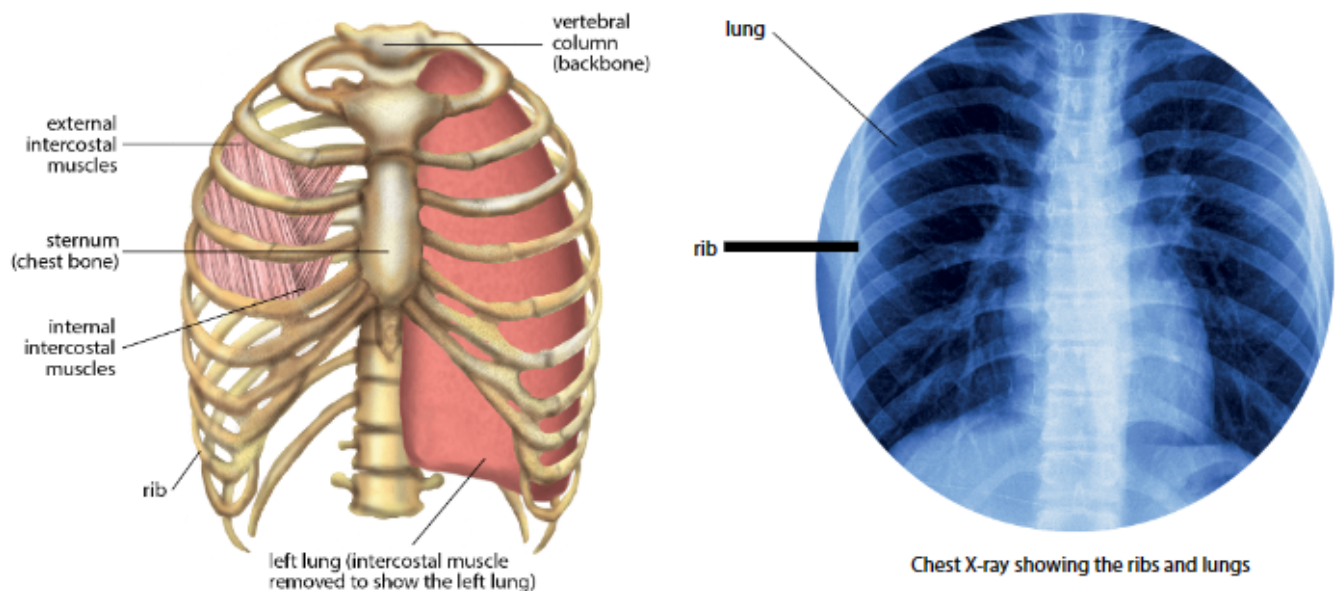


Figure 7.15 The ribs and the intercostal muscles

The thorax is separated from the abdomen by a dome-shaped sheet called the **diaphragm**. The diaphragm is made of muscle and elastic tissue. When the diaphragm muscles contract, the diaphragm flattens downwards, and when they relax, the diaphragm arches upwards again. The workings of the intercostal muscles and the diaphragm change the volume of the thoracic cavity (Figures 7.16 and 7.19).

Inspiration (Inhalation)

Note that the words 'upwards' and 'downwards' are used with reference to a person standing in the upright position.

When you **inspire**, the following events take place:

- Your diaphragm muscle contracts, and the diaphragm flattens.
- Your external intercostal muscles contract while your internal intercostal muscles relax.
- Your ribs move upwards and outwards. Your sternum also moves up and forward.
- The volume of your thoracic cavity increases.
- Your lungs expand and air pressure inside them decreases as the volume increases.
- Atmospheric pressure is now higher than the pressure within your lungs.
- Air moves into the lungs.



Link

Refer to Figure 7.8 in Section 7.2 to recall the position of the thorax



Word Alert

Inspire: Inhale, breathe in

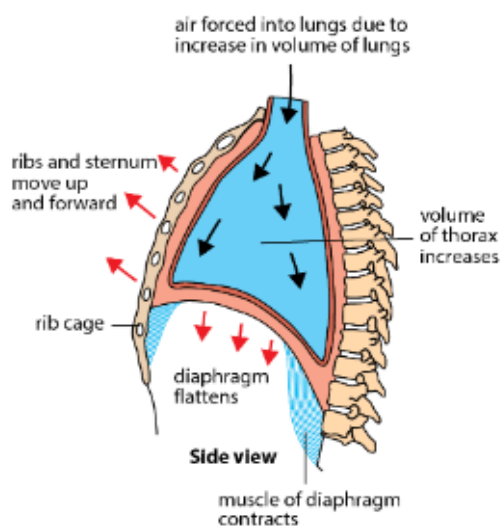


Figure 7.16 Movement of rib cage and diaphragm during inspiration

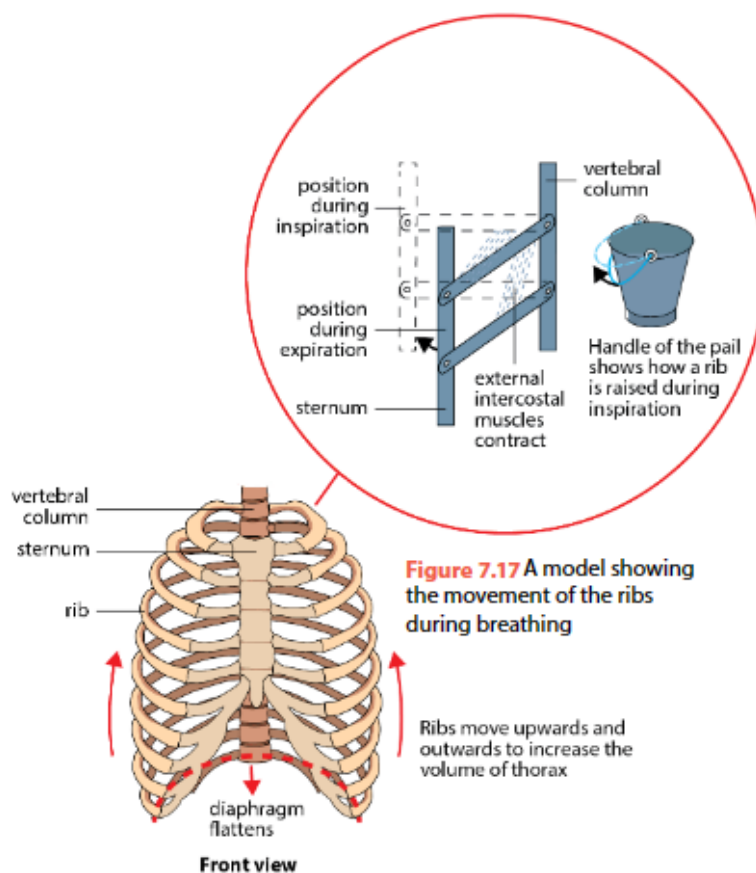


Figure 7.17 A model showing the movement of the ribs during breathing

The path of the air into the lungs is shown below:

external nostrils → nasal passages → pharynx → larynx → trachea → bronchi → bronchioles → alveoli

Model to Show How Breathing Works

Figure 7.18 shows a model that is used to demonstrate the action of the diaphragm. When the rubber sheet (diaphragm) is pulled down, the increase in volume causes a drop in the air pressure inside the bell jar. Atmospheric pressure outside is now higher than that in the jar. This forces air to enter and fill up the balloons (lungs).

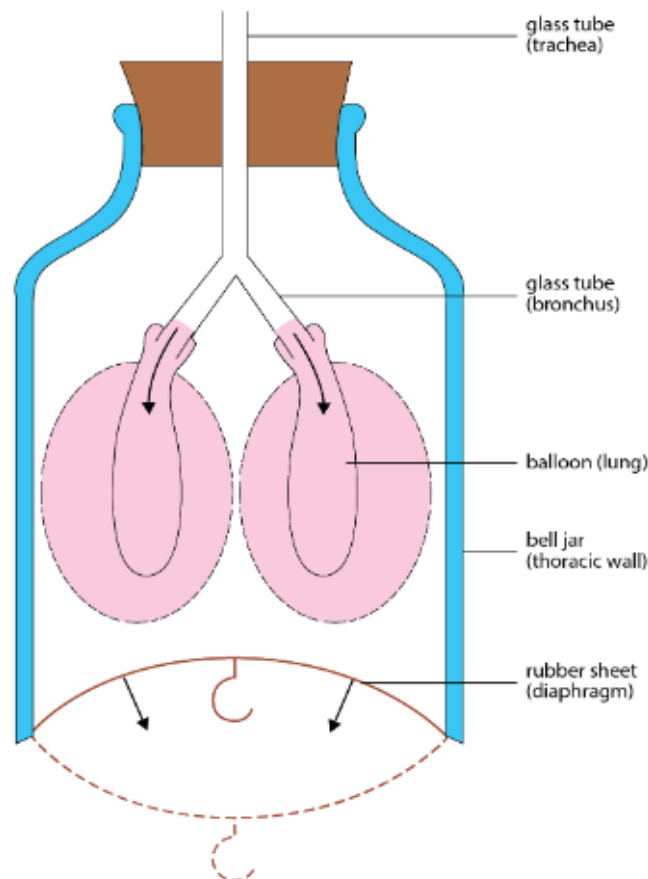


Figure 7.18 Model showing the actions of the diaphragm in the human gas exchange system



Word Alert

Expire: exhale, breathe out



Helpful Note

RICE and ERIC

Here is an easy way to remember what happens to your intercostal muscles when you are breathing.

When you inhale, you ...

Relax your
Internal intercostal
muscles and
Contract your
External intercostal
muscles.

When you exhale, your ...

External intercostal
muscles
Relax and your
Internal intercostal
muscles
Contract.

Expiration (Exhalation)

When you **expire**, the following events take place:

- Your diaphragm muscle relaxes and the diaphragm arches upwards.
- Your internal intercostal muscles contract while your external intercostal muscles relax.
- Your ribs move downwards and inwards. Your sternum also moves down to its original position.
- The volume of your thoracic cavity decreases.
- Your lungs are compressed and air pressure inside them increases as the volume decreases.
- Pressure within the lungs is now higher than atmospheric pressure. The air is forced out of your lungs to the exterior environment.

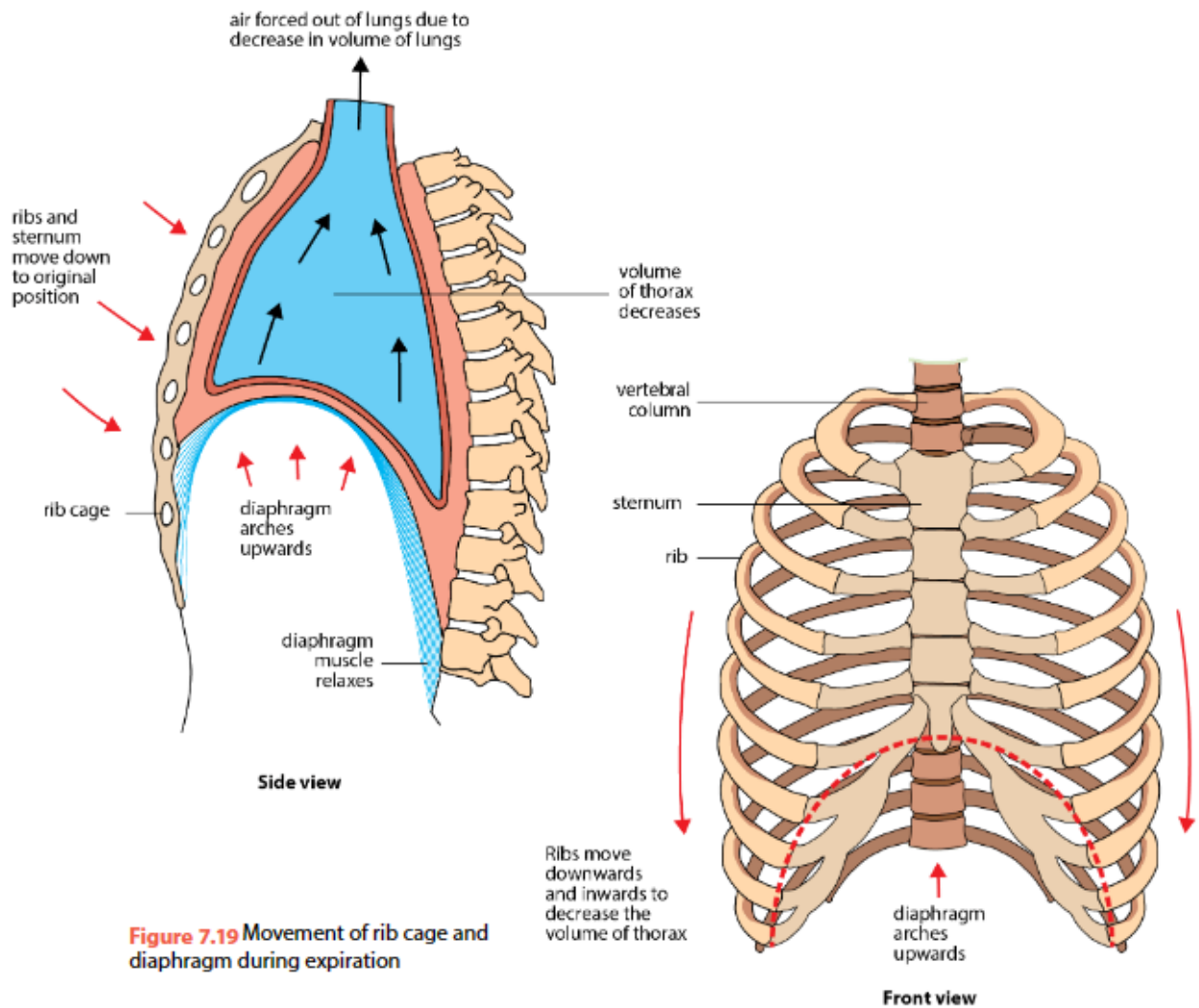


Figure 7.19 Movement of rib cage and diaphragm during expiration



Tech Connect

A mechanical ventilator is a machine that can pump air into a person's lungs, just like when one breathes in. It can also pump air out of the lungs, just like when one breathes out.

During the COVID-19 pandemic, ventilators were in high demand in hospitals. Patients with inflamed airways due to the Covid-19 virus experienced breathing difficulties. Doctors had to put them on ventilators to help them breathe. These important pieces of technology have saved the lives of many seriously ill patients during the pandemic.



Figure 7.20 A mechanical ventilator helps patients to breathe.



Word Alert

Inspired: inhaled

Expired: exhaled

How Does Inspired Air Differ from Expired Air?

Inspired air differs in composition from **expired** air. Some water evaporates from the surfaces of the alveoli. This explains why the air we breathe out is saturated with water vapour. In the lungs, oxygen has been absorbed into the bloodstream, but carbon dioxide is released from the blood. This explains why the air we breathe out has a lower oxygen concentration but a higher carbon dioxide concentration than the air we breathe in. Some heat also escapes from the blood into the alveolar air. The differences between inspired and expired air are summarised in Table 7.1.

Table 7.1 Differences between inspired and expired air

Component	Inspired Air	Expired Air
Oxygen	Higher	Lower
Carbon dioxide	Lower	Higher
Nitrogen	About the same	About the same
Water vapour	Variable (rarely saturated)	Saturated
Dust particles	Variable but usually present	Little, if any
Temperature	Variable	About body temperature (37 °C)



Helpful Note

Expired air contains about 16.4% of oxygen. Not all the oxygen that is inspired is used for respiration.

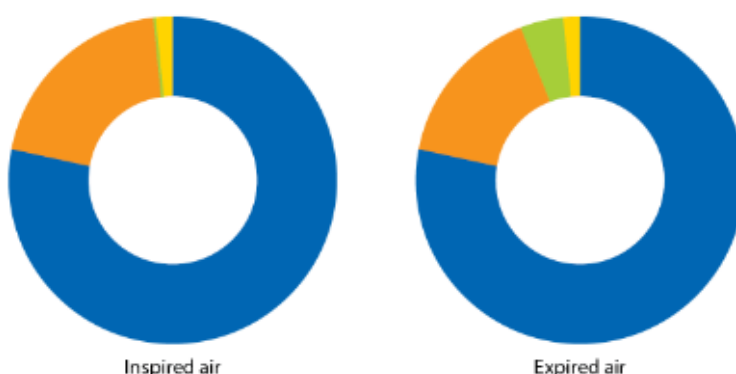


Figure 7.21
Composition of inspired and expired air (refer to Table 7.1 for colour codes)

The differences between inspired and expired air can be investigated by carrying out the following experiments.

Let's Investigate 7.3

Aim

To find out if the amount of carbon dioxide in inspired air is different from expired air

Procedure

- 1 Fit two conical flasks, containing about the same volume of limewater, with glass tubings as shown in Figure 7.22.

- 2 Place the open end of the T-tube in your mouth. Gently breathe air in and out through your mouth. As air is breathed in, atmospheric air (i.e. inspired air) is drawn into tube C. It bubbles through the limewater in flask A and up through tube D into the mouth. When air is breathed out, the expired air passes through tube E and into the limewater in flask B and out into the atmosphere through tube F.

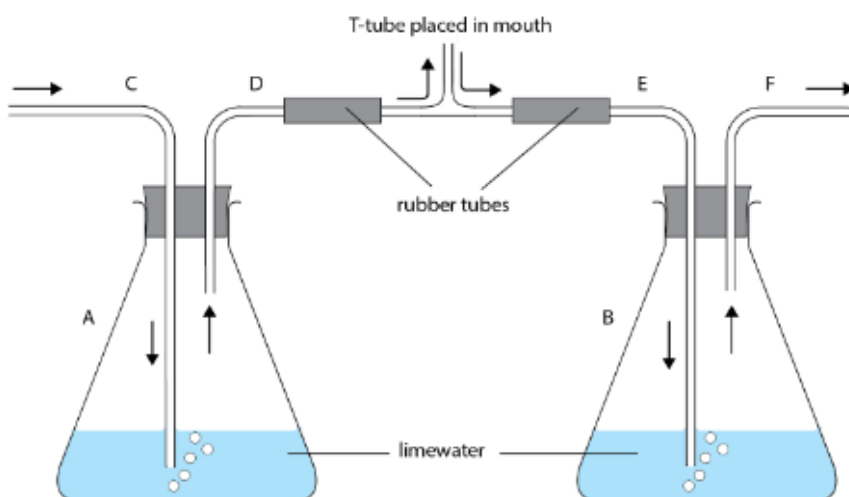


Figure 7.22 Investigating the amount of carbon dioxide in inspired and expired air

Questions

- 1 After a few minutes, what do you observe in the two flasks?
- 2 What can you conclude from this investigation?



Link

Practical Workbook
Experiment 7B

Let's Investigate 7.4

Aim

To find out if the temperature of inspired air is different from that of expired air

Procedure

- 1 Use a thermometer to determine the temperature of the room.
- 2 Then, hold the bulb of the thermometer close to your mouth and breathe air onto it continuously. Record the temperature of the expired air.

Question

- 1 Which has a higher temperature, inspired or expired air?



Helpful Note

How Much Air Do We Breathe In and Out of the Lungs?

Only some of the air in your lungs is changed in each breathing cycle (Figure 7.23). The amount of air changed varies with the depth of breathing. It has been estimated that in each normal breathing cycle, about 500 cm^3 of air enters the lungs, and about the same volume is breathed out. This volume of air is known as **tidal air**.

When you take a deep breath, you take in a volume of air that is larger than your tidal air. The additional volume of air is called the **complemental air** and it is about 1500 cm^3 . Similarly, about 1500 cm^3 can be forced out after normal expiration. This is called **supplemental air**.

Take the deepest breath you can, then blow out all the air you can. The total volume of air exhaled during forced exhalation is about $3500\text{--}4000 \text{ cm}^3$. This is the **vital capacity** of the lungs.

vital capacity = tidal air + complemental air + supplemental air

No matter how hard you try to force all the air out of your lungs, there will always be some left behind. This volume of air, estimated to be about 1500 cm^3 , is called **residual air**.

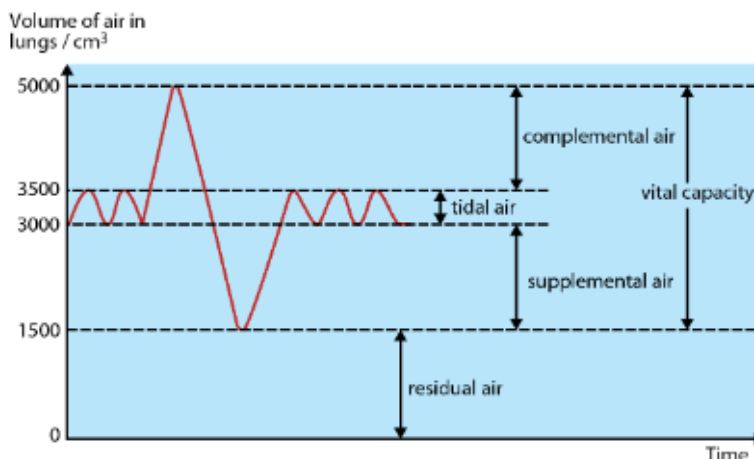


Figure 7.23 Graph showing the amount of air in the lungs during breathing

Let's Practise 7.3

1 A **spirometer** is an instrument used to measure the volume of air that enters and leaves the lungs during breathing. In an experiment, a man was at rest for one minute and then exercised for one minute. His rate of breathing was recorded in Figure 7.24.

- How many breaths per minute was the man taking while at rest?
- How much air was taken into his lungs during the one-minute rest?
- What changes took place in his breathing during exercise?
- Which part of the graph, A or B, represents expiration?

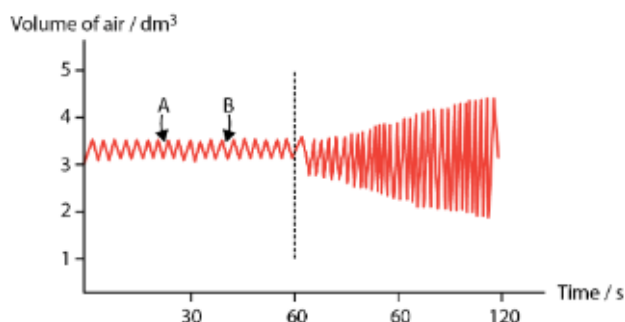


Figure 7.24



Link

Theory Workbook
Worksheet 7D

7.4 What Effects Does Tobacco Smoke Have on Human Health?

Learning Outcome

- State the major toxic components of tobacco smoke — nicotine, tar and carbon monoxide, and describe their effects on health.

Cigarette manufacturers used to spend a huge amount of money for cigarette advertisement on media such as TV and billboards. They paid powerful influencers such as celebrities to show how smoking was cool and trendy. Today, we hardly see any cigarette advertisements. What has changed? As more and more medical evidence emerged to show the harmful effects of smoking on health, restrictions were imposed over the last 50 years. In Singapore, smoking is banned in most public spaces and forbidden for those under a certain age limit. Instead of cigarette advertisements, you will see more quit-smoking campaigns. Why is smoking now considered bad?

Tobacco smoke contains more than 4000 chemicals, most of which are harmful to the body. Figure 7.25 lists some of the components that have been linked to health problems.

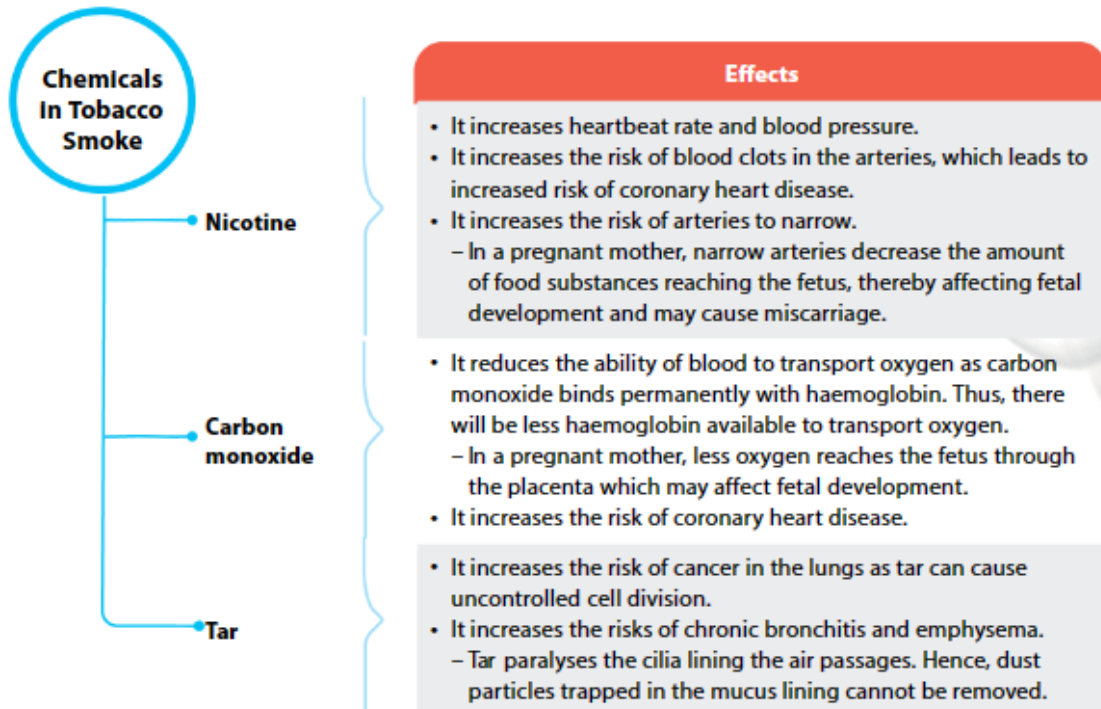


Figure 7.25 Chemicals in tobacco smoke and their harmful effects



What Diseases Are Caused by Tobacco Smoke?

Frequent exposure to tobacco smoke increases the risk of a person getting diseases of the respiratory system, such as chronic bronchitis, emphysema and lung cancer. The World Health Organisation (WHO) estimates that more than 8 million people die each year due to tobacco use.

Chronic Bronchitis

Prolonged exposure to irritant particles that are found in tobacco smoke may cause chronic bronchitis. In chronic bronchitis:

- The epithelium lining of the air passages (airways), for example, the bronchi, becomes inflamed.
- Excessive mucus is secreted by the epithelium.
- The cilia on the epithelium are paralysed. Mucus and dust particles cannot be removed.
- The air passages become blocked, making breathing difficult.
- In order to breathe, persistent coughing occurs to clear the air passages (Figure 7.26). This increases the risk of getting lung infections.



Figure 7.26
Chronic bronchitis may cause a smoker to cough persistently.

Emphysema

Persistent and violent coughing due to bronchitis may lead to emphysema. In emphysema:

- The partition walls between the alveoli break down due to persistent and violent coughing (Figure 7.27).
- This results in a decreased surface area for gaseous exchange.
- The lungs lose their elasticity and become inflated with air.
- Breathing becomes difficult. Wheezing and severe breathlessness result.

When a person has chronic bronchitis and emphysema, he is said to suffer from **chronic obstructive lung disease**.



Figure 7.27 Diagram showing a healthy lung damaged by emphysema



Figure 7.28
Healthy lungs (top) and smoker's lungs (bottom)

Lung Cancer

Studies have shown that the risk of lung cancer increases when a person smokes tobacco. Figure 7.28 shows the lungs of a smoker compared to a pair of healthy lungs. According to the Singapore Health Promotion Board, smoking-related diseases in Singapore alone accounts for about seven premature deaths each day.

Cancer is the uncontrolled division of cells producing outgrowths or lumps of tissues. Apart from lung cancer, smoking also increases the risk of cancers of the mouth, throat, pancreas, kidneys and urinary bladder.



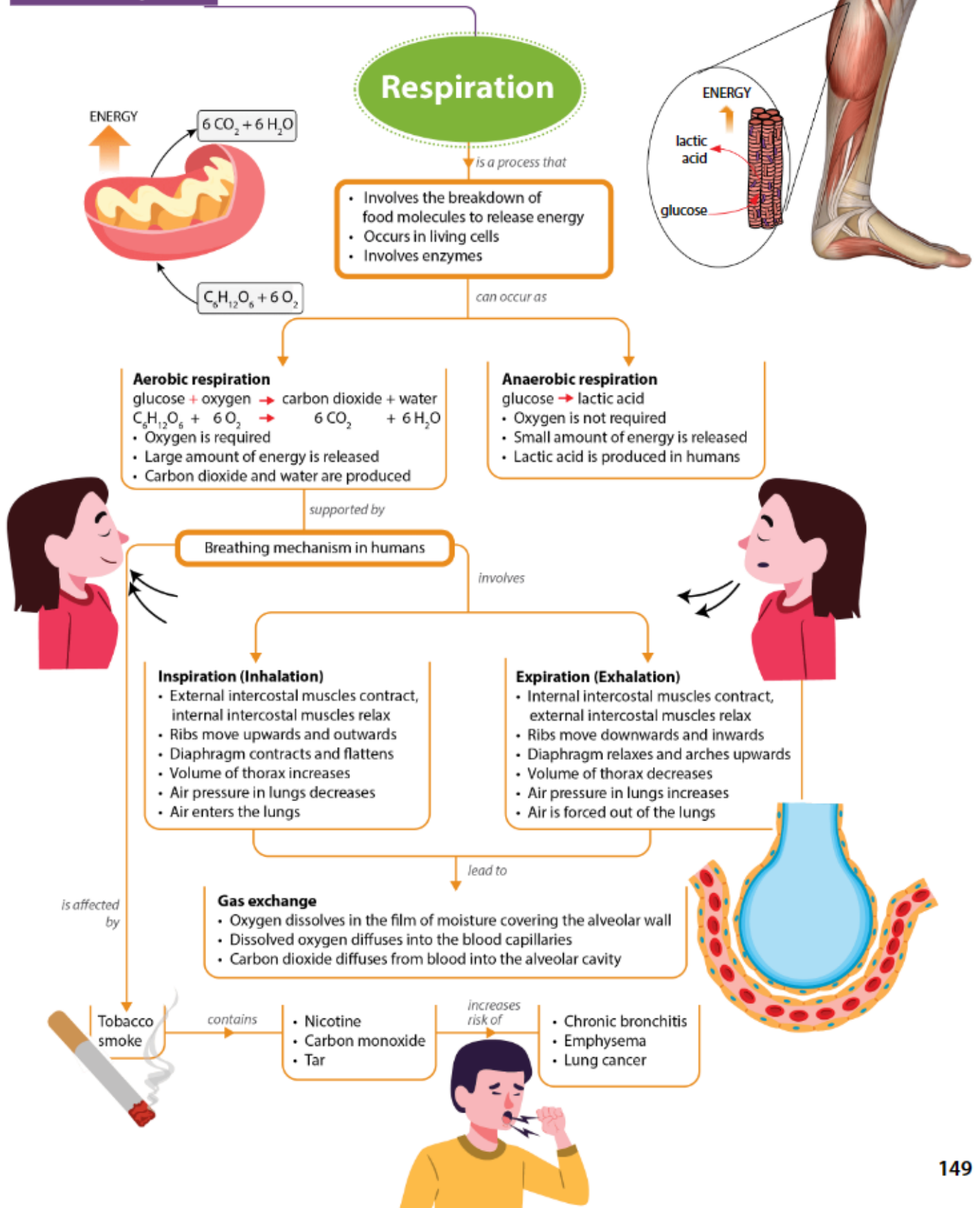
Link

Theory Workbook
Worksheet 7E

Let's Practise 7.4

- 1 (a) Name **three** harmful chemicals found in cigarette smoke.
(b) State the effects of these chemicals on the body.
- 2 Describe how smoking can lead to chronic bronchitis.

Let's Map It



Let's Review

Section A: Multiple-choice Questions

- 1 Which changes occur in the blood as it flows through muscles during a vigorous activity?

	Blood Temperature	Concentration of Lactic Acid in Blood
☐ A	Increases	Increases
☐ B	Increases	Decreases
☐ C	Decreases	Increases
☐ D	Decreases	Decreases

- 2 When a person is resting, the amount of oxygen in his expired air is

- ☐ A higher than that in his inspired air.
☐ B lower than that in his inspired air.
☐ C higher than that in his expired air when he is exercising.
☐ D the same as the amount of oxygen in the air.

Section B: Structured Questions

- 1 (a) State **two** similarities between aerobic and anaerobic respiration.
 (b) State **three** differences between aerobic and anaerobic respiration.
- 2 (a) During a 100 m race, the energy that the athlete uses comes from both aerobic and anaerobic respiration. Explain why.
 (b) Write down the word equation for anaerobic respiration in muscles.

- 3 Figure 7.29 shows part of the respiratory system.

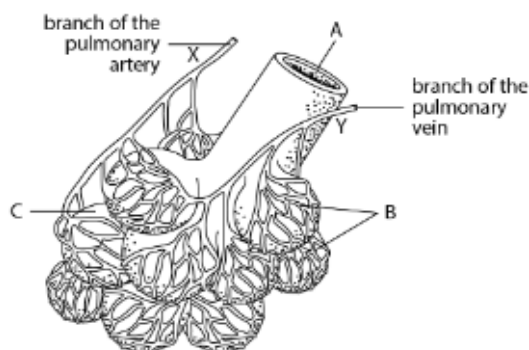


Figure 7.29

- (a) Name the structures labelled A, B and C.
 (b) What is the difference in the amount of
 (i) carbon dioxide,
 (ii) oxygen
 in the blood at X as compared to Y?

Section C: Free-response Questions

- 1 What do you understand by the term *oxygen debt*?
- 2 In what ways are the lungs adapted for the efficient absorption of oxygen?
- 3 How does expired air differ from inspired air? Suggest reasons for the differences.
- 4 Suggest reasons why gas exchange is less efficient in the lungs of a person with emphysema.

CHAPTER

08 Excretion in Humans



What You Will Learn



- Why is excretion necessary?
- What makes up the human urinary system?
- How is urine formed?
- What is osmoregulation?
- What happens when the kidneys fail?

On a fateful day in 2019, Singaporean John Low, went out diving at sea. Due to bad weather, his boat sank, leaving him drifting for three days without food and water. Miraculously, John survived the ordeal. He tried drinking sea water initially, but it was a bad idea. Why do you think this was so? How do you think he could survive for that period without fresh water to drink?



8.1 Why Is Excretion Necessary?

Learning Outcome

- Define excretion and explain the importance of removing nitrogenous and other compounds from the body.

Every day, we consume different kinds of foods. Some substances in these foods are useful and get absorbed into our bodies, while others are not needed. What happens to those substances that are not useful?

Numerous chemical activities occur within our body cells all the time. These are called **metabolic** activities. Some metabolic activities produce substances that are harmful or toxic to our bodies. They are called **metabolic waste products** or **excretory products**. These, together with any other substances that are not needed, have to be removed. How do our bodies get rid of them?

What Are Some Metabolic Waste Products?

Carbon Dioxide

Carbon dioxide is a product of aerobic respiration. The carbon dioxide level in our blood is usually not harmful. However, in certain cases when there is an abnormally high level of carbon dioxide in the blood, a condition called hypercarbia occurs. The person may suffer from headache, confusion, rapid breathing and premature heartbeats.

Urea

How is urea produced?

You have learnt that the digestive system breaks down proteins into amino acids. Absorbed amino acids are transported to the liver, distributed round the body and then assimilated. The liver is involved in the assimilation of amino acids. It uses amino acids to synthesise the proteins found in blood plasma. These plasma proteins include fibrinogen, which is essential for the clotting of blood.

If we consume more proteins than we need, we will have excess amino acids in the blood. Excess amino acids are transported to the liver where they are **deaminated** through a process called **deamination**. During deamination, part of the amino acid molecule is removed and converted to urea. Urea is then removed by the kidneys.

Is urea in the blood harmful?

Urea is a waste product formed from the breakdown of proteins (Figure 8.1). Normally the concentration of urea in the blood is not harmful. However, abnormally high urea concentration in the blood may cause abdominal pain, nausea or vomiting. In rare cases, it can even result in an irregular heartbeat and muscle cramps.



Figure 8.1 Eating too much meat, which is high in protein, can increase the concentration of urea in the blood.



Link

Recall the role of the liver in urea formation and deamination which you have learnt in Chapter 5.

**Word Alert**

Deficiency: not having enough

Mineral Salts or Ions

Our bodies need mineral salts. **Deficiency** of certain ions may result in deficiency diseases, for example, a lack of calcium can result in weakening of the bones or osteoporosis. Why, then, must our kidneys remove ions?

Excess salts or ions in the blood can be harmful. They may lower the water potential in the blood plasma, i.e. make the blood plasma more concentrated. Water may pass out of the tissue cells into the blood by osmosis. The cells may become dehydrated. The kidneys help to remove excess salts from the body.

So even if the chemicals are useful to our bodies, they may be harmful if they are in excess of the body's requirements.

Water

Water is essential to life. It is produced during aerobic respiration. Hence, it is also a metabolic product.

However, excess water in the body is harmful. It will increase the water potential in the blood plasma. By osmosis, water will enter the tissue cells. The cells may swell and burst. Hence, excess water in the body has to be removed.



Figure 8.2 These foods contain mineral salts such as calcium, iron, potassium, zinc and magnesium. Excess mineral salts in the body can be harmful and needs to be removed.

What Is Excretion?

- **Excretion** is the removal of metabolic waste products, toxic substances and substances in excess of the body's requirements.

The lungs excrete carbon dioxide. The kidneys excrete urea and excess salts and water. Organs involved in excretion are shown in Table 8.1.

Table 8.1 Main excretory products and their excretory organs

Excretory Products	Excretory Organs	Excreted As
Carbon dioxide	Lungs	Gas in expired air
Excess mineral salts	Kidneys Skin	Constituent of urine Constituent of sweat
Excess water	Kidneys Skin	Constituent of urine Constituent of sweat
Urea	Kidneys Skin	Constituent of urine Constituent (traces) in sweat

Why Is Excretion Important?

The body excretes metabolic waste products (e.g. urea) and toxic substances so that they do not accumulate to a level that becomes harmful to the body.

You have learnt that certain waste products in the body are removed through sweat. Sweat may lead to an unpleasant body odour. Some people use an antiperspirant, which is a chemical that reduces sweating. Antiperspirant that contains aluminium blocks the sweat ducts and reduces the amount of sweat that reaches the skin surface.

Should we use antiperspirants when we are exercising? Figure 8.3 shows three people giving their views on this. Evaluate the view of each person. Discuss your views with your friends and see if you can reach a conclusion. How can you design investigations to find out which viewpoint is the most accurate?



Hint

- Recall the role of sweat in excretion.
- Sweat helps our bodies to lose heat when it evaporates from the skin.
- Consider what would happen if the production of sweat decreases.

Figure 8.3 Three people are giving their views on the use of antiperspirants. Comment on their views.

Let's Practise 8.1

- (a) State what you understand by each of the following terms:
 - metabolic waste products
 - excretion
- (b) Give **two** examples of excretion, and for each, state the excretory products.

8.2 What Makes Up the Human Urinary System?

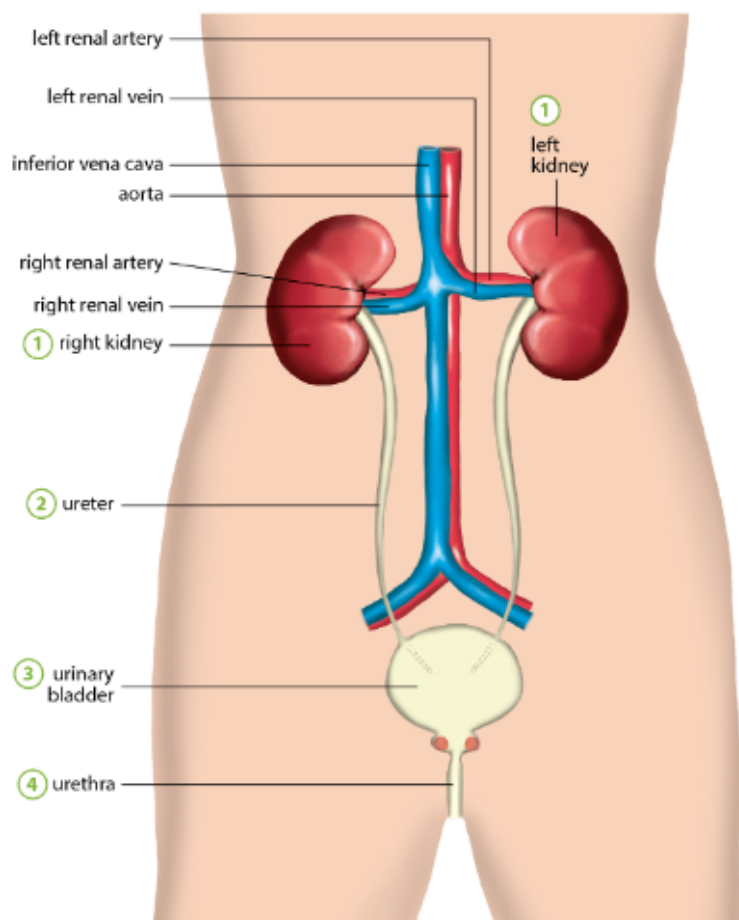
Learning Outcome

- Identify the kidneys, ureter, bladder and urethra and state their functions in excretion.

There is an old saying “when you gotta go, you gotta go”, referring to the periodic need to go to the toilet to relieve ourselves. The feeling of urgency when looking for a toilet is familiar to us all. While we have learnt that urine is a means of flushing out waste products and excess substances from the body, how does the human body gather all these and concentrate them to produce urine?

The human urinary system consists of a pair of **kidneys**, a pair of **ureters**, a **urinary bladder** and the **urethra** (Figure 8.4).

- The **kidneys** are bean-shaped organs that are embedded in a mass of fat in the abdominal cavity. The average size of a human kidney is 10 to 13 cm long and about 5 to 7 cm wide. The kidneys lie just above the waistline. The left kidney is slightly higher than the right kidney. The main function of the kidneys is to excrete urea and excess salt and water as urine.



- The **ureter** is a narrow tube that connects the kidney to the urinary bladder. Urine from each kidney passes through the ureter to the urinary bladder.
- The **urinary bladder** is an elastic muscular bag located in front of the rectum. It stores urine.
- The **urethra** is the duct through which urine passes from the bladder to outside of the body.



Disciplinary Idea

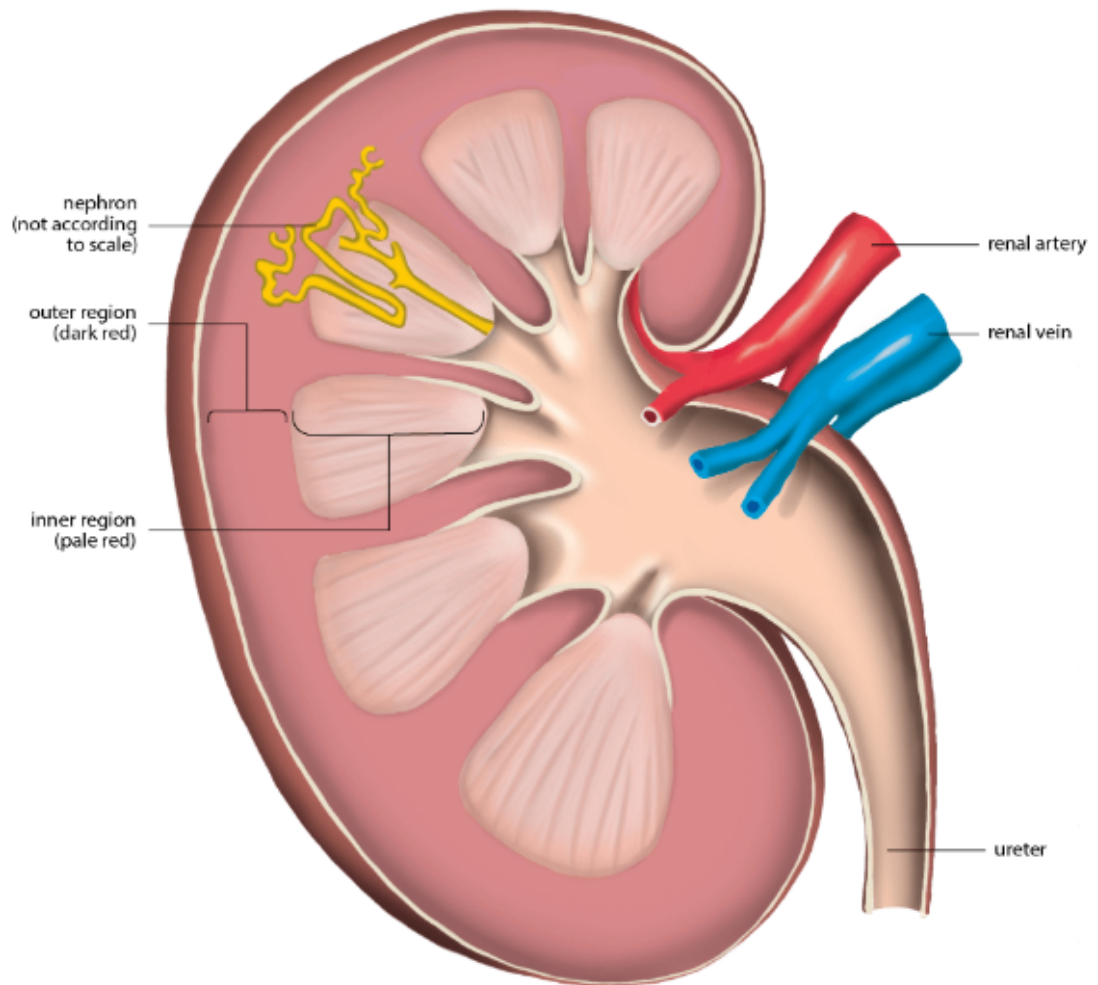
System

The human urinary system consists of different parts working together to remove waste products, toxic substances and substances in excess of the body's requirements from the body.

Figure 8.4 Human urinary system

Structure of the Kidney

Figure 8.5 shows the structure of the human kidney. If a kidney is dissected longitudinally, an outer dark red region and an inner pale red region are visible. Inside the kidney, there are numerous nephrons. **Nephrons** are the basic functional units of the kidney. They are tiny kidney tubules where urine is formed. The kidney is connected to the ureter, which drains the urine into the urinary bladder for removal.



Link

Practical Workbook
Experiment 8A

Figure 8.5 Diagram of a section through a kidney showing the regions and the position of a nephron

Structure of a Nephron

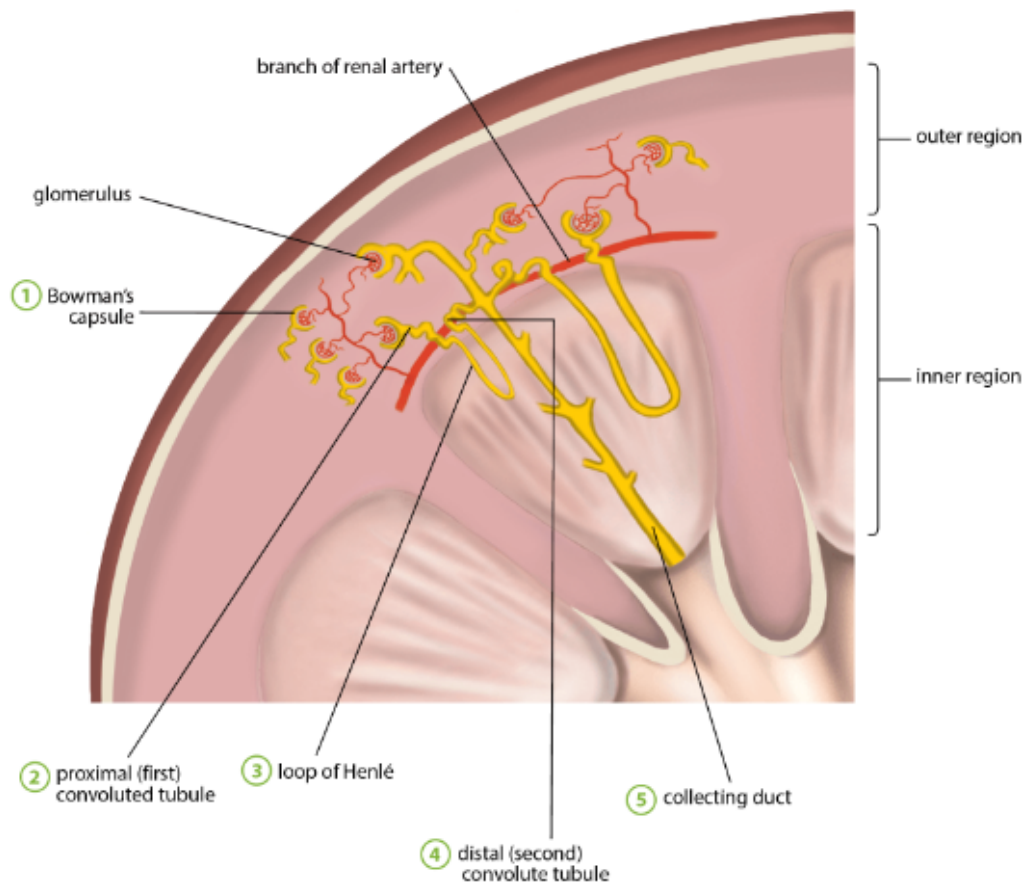
The four main parts of a nephron are: the *Bowman's capsule*, *proximal (first) convoluted tubule*, *loop of Henlé*, and *distal (second) convoluted tubule* (Figure 8.6). Several nephrons open into a tube called the *collecting duct*.

- ① **Bowman's capsule**
Each nephron begins in the outer region of the kidney as a cup-like structure called the **Bowman's capsule**.
- ② **Proximal (first) convoluted tubule**
The capsule leads into a short, convoluted tubule, which straightens out as it passes into the inner region of the kidney. The convoluted part of the tubule is called the **proximal (first) convoluted tubule**.
- ③ **Loop of Henlé**
In the inner region of the kidney, the tubule extends further in and makes a U-turn back into the outer region. The U-shaped portion of the tubule is known as the **loop of Henlé**.
- ④ **Distal (second) convoluted tubule**
When the tubule enters the inner region of the kidney again, it becomes convoluted again. This part of the tubule is called the **distal (second) convoluted tubule**.
- ⑤ **Collecting duct**
The tubule then opens into a collecting duct that runs straight through the inner region. It eventually opens into a funnel-like space that leads to the ureter.



Word Alert

Convoluted: highly coiled, folded, twisted



Disciplinary Idea

Structure and Function

The structure of the nephron is designed to filter excretory waste products such as urea and allow reabsorption of nutrients.

Figure 8.6 Section of kidney showing the complete structure of two nephrons and the arterial supply (L.S.)

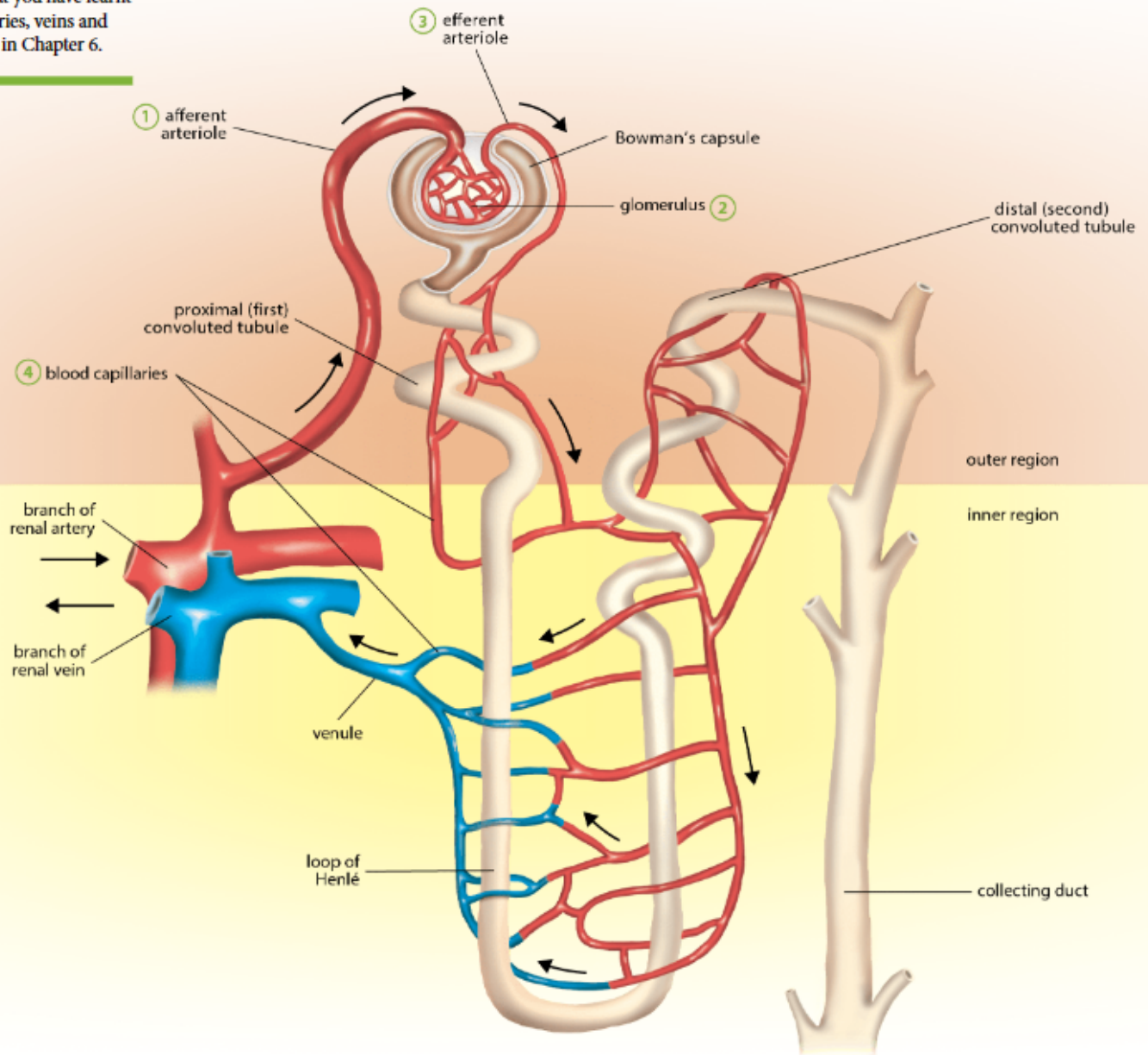


Link

Recall what you have learnt about arteries, veins and capillaries in Chapter 6.

Blood Capillaries Around the Nephron

Blood enters the kidney by the renal artery and leaves the kidney by the renal vein. Nephrons in the kidney are surrounded by blood vessels that are connected to the renal artery and renal vein (Figure 8.7).



① A small branch of the renal artery called the **afferent arteriole** carries blood into the glomerulus.

② The **glomerulus** is a knot of blood capillaries in the Bowman's capsule.

③ An **efferent arteriole** transports blood away from the glomerulus.

④ The blood continues into the blood capillaries surrounding the nephron. These **blood capillaries** eventually lead into a branch of a the renal vein.

Figure 8.7 Diagram of a nephron or kidney tubule with its blood supply

Let's Practise 8.2

- 1 Figure 8.8 shows a section of a kidney.
- Name the parts labelled A–D.
 - State the function of D.

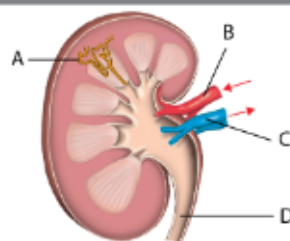


Figure 8.8 Section of a kidney



Link

Theory Workbook
Worksheet 8A

8.3 How Is Urine Formed?

Learning Outcome

- Outline the function of the nephron with reference to ultrafiltration and selective reabsorption in the production of urine.

The urine that comes out from our bodies may vary in colour. Sometimes it is dark yellow, and sometimes paler and almost colourless. After eating certain foods, our urine can be very dark or particularly pungent. Urine can be tested to detect certain medical conditions. What is in urine and what affects its composition?

Urine formation involves two main processes: *ultrafiltration* and *selective reabsorption*.

Ultrafiltration

The first stage in urine formation is **ultrafiltration**. It involves the following:

- The afferent arteriole being wider than the efferent arteriole creates a high blood pressure in the glomerulus.
- Blood plasma is forced out of the glomerular blood capillaries into the Bowman's capsule.
- The filtered blood plasma is known as the **glomerular filtrate**. It contains small, soluble molecules (e.g. salts, water, glucose, amino acids and waste products such as urea) that are forced out into the Bowman's capsule.



Word Alert

Filtrate: liquid that has passed through a filter
Impermeable: not permeable; does not allow substances to pass through

How Is the Glomerulus Suited to Urine Formation?

- The glomerulus is a knot or network of blood capillaries (Figure 8.9). These provide a large surface area for the filtration process.
- The blood capillaries have walls one-cell thick. There are tiny pores in the capillary wall.
- The blood capillaries are covered by a thin partially permeable membrane. It only allows very small soluble molecules or ions to pass through. It is **impermeable** to blood cells, platelets and large molecules such as proteins.

Figure 8.9 Electron micrograph of a glomerulus

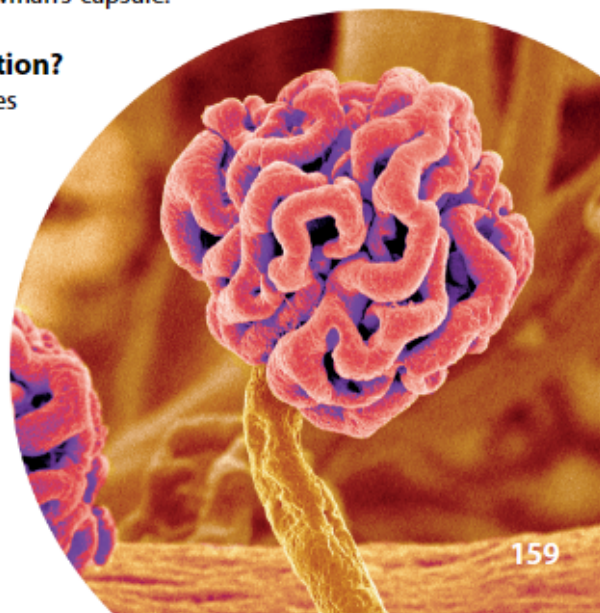


Figure 8.10 shows how the glomerulus filters blood to form urine.

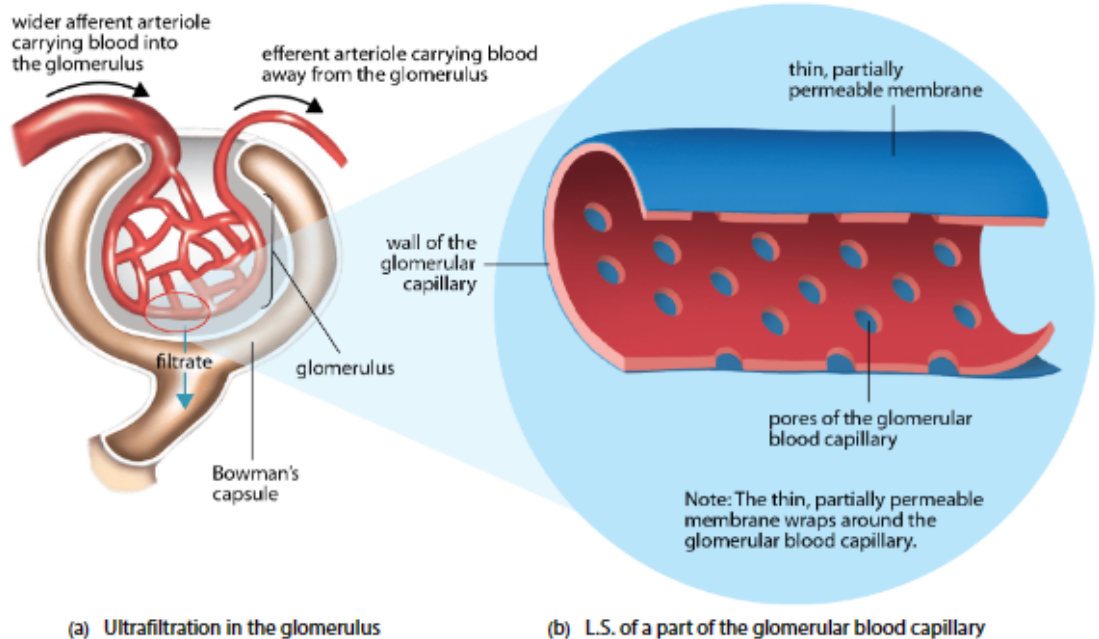


Figure 8.10 The glomerulus filters blood to form urine.

Selective Reabsorption

In a normal adult, about 120 cm^3 of glomerular filtrate is formed in the kidneys every minute. If this amount of filtrate were allowed to pass out as urine, the body would lose too much water and other useful substances. The body would soon be dehydrated.

Thus, as the glomerular filtrate passes along the nephron, useful substances are reabsorbed into the surrounding blood capillaries. This process is called

selective reabsorption because only substances that the body requires are reabsorbed. In this process, the following occurs:

- Most of the water is reabsorbed by osmosis.
- Some salts are reabsorbed by active transport.
- All the glucose and amino acids are reabsorbed by active transport.

Waste products such as urea and excess water and mineral salts are passed out of the nephron as urine.

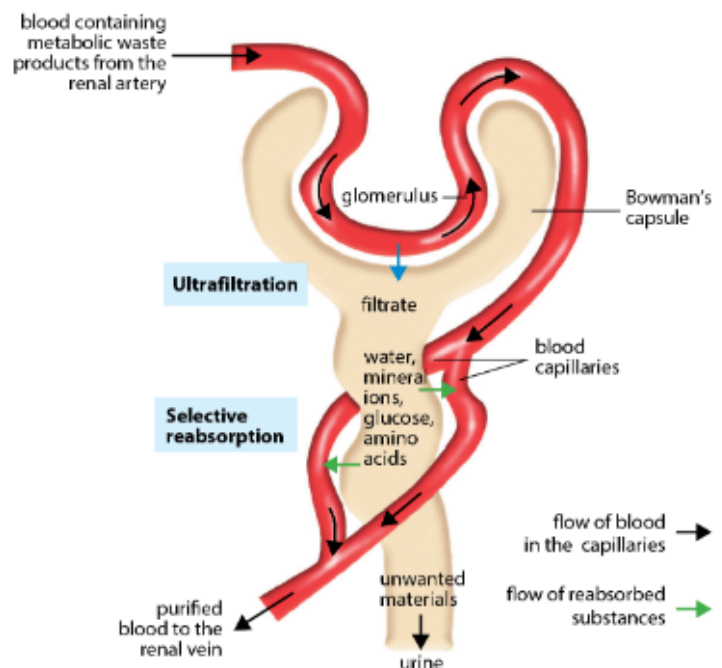


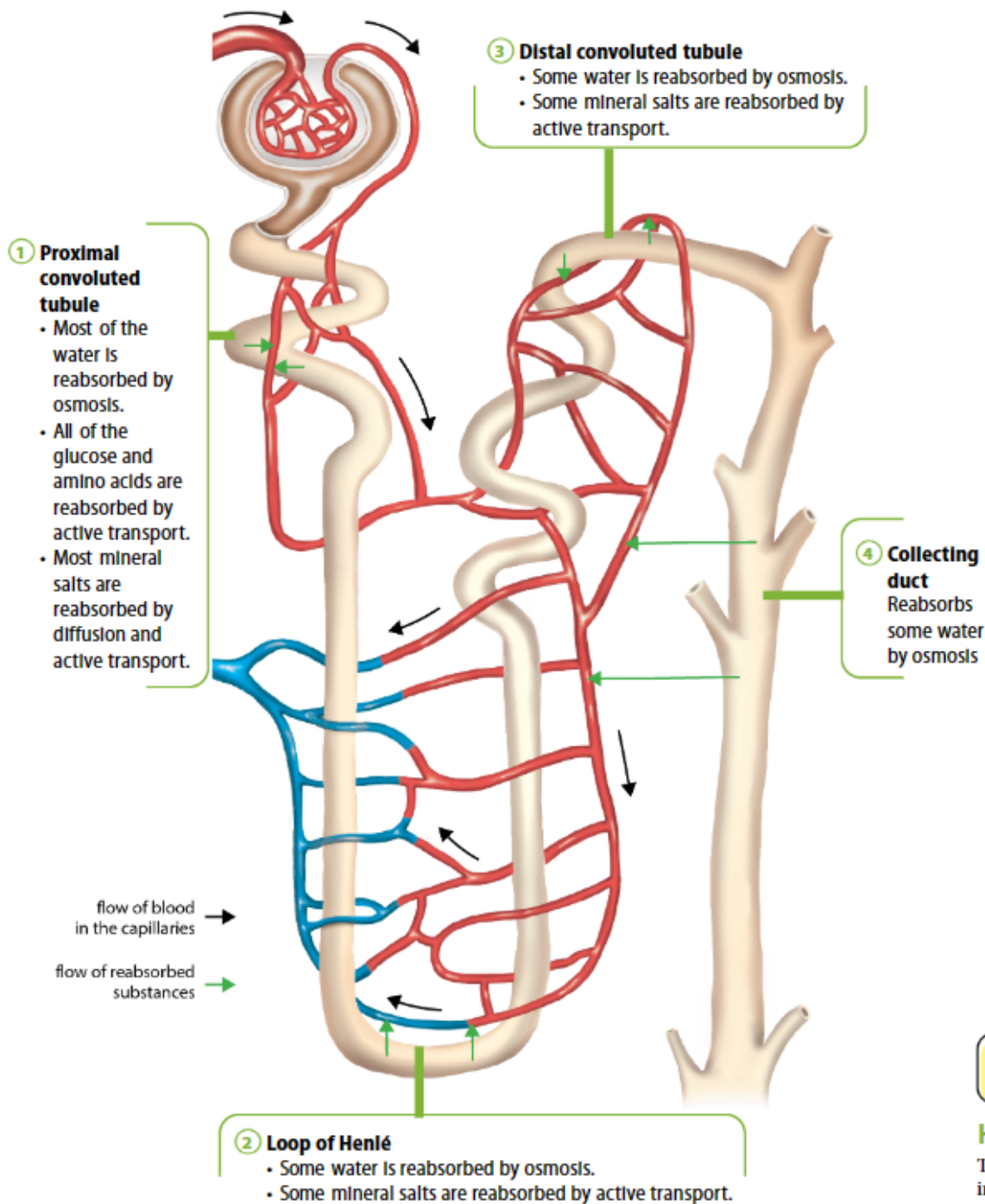
Figure 8.11 Overview of urine formation



Link

In active transport, the protein pump in the cell membrane uses energy from respiration to absorb substances against a concentration gradient. Recall what you have learnt in Chapter 2.

Figure 8.12 shows the different substances that are reabsorbed along the different parts of the nephron.



Helpful Note

The concentration of urea in the filtrate increases as it moves through the nephron.

Figure 8.12 Selective reabsorption along the nephron

Let's Investigate 8.1

The blood pressure in the glomerulus needs to be high in order to filter the blood.

How do the differing diameters of the afferent and efferent arterioles increase the blood pressure in the glomerulus? Think of an analogy to show this.

Hint You may want to use a pipe and a hose.



Past to Present

Did you know that urine was the primary way to diagnose patients from ancient times until the Victorian era? The study of urine began more than 6000 years ago, when Babylonian and Egyptian physicians examined the “divine fluid”. The Greek physician, Hippocrates, knew that the kidneys filter blood but did not quite know how. It was only till six centuries later, that Galen from Rome determined urine as a filtrate of the blood.

In the 7th century, a physician by the name of Theophilus Protospatharius performed the first laboratory technique on urine, boiling it to precipitate excess proteins. From the 17th century, scientists started to conduct chemical tests to identify the urine from healthy and ill individuals. In the early 19th century, scientists developed new methods to study urine samples. These included the use of yeast fermentation to detect the presence of sugar in blood, and methods to detect the presence of some types of bacteria which commonly caused urinary tract infections.

Over the years, urine continues to be used by physicians who conduct chemical tests and study cells and microbes in urine samples to understand the health of patients.



Figure 8.13 Urine samples are often taken from patients for laboratory tests to determine the health conditions of the patient.

Let's Practise 8.3

- 1 (a) Name **one** substance in the blood plasma that does **not** pass out of the glomerulus.
- (b) (i) Name **two** substances in the blood plasma that pass out of the glomerulus into the Bowman's capsule, but are normally absent from the urine in humans.
- (ii) What happens to these two substances at the nephron?
- 2 Refer to Figure 8.14. State **two** differences between the blood in A and B.

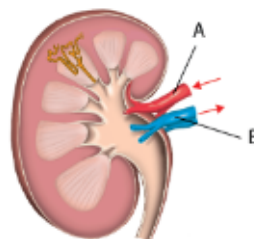


Figure 8.14 Section of a kidney



Link

Theory Workbook
Worksheet 8B

8.4 What Is Osmoregulation?

Learning Outcome

- Outline the role of antidiuretic hormone (ADH) in osmoregulation.

Do fish produce urine? Yes, they do. Fish, like humans, have kidneys. The amount of urine produced depends on whether the fish lives in fresh water or sea water. Freshwater fish produce a larger volume of urine than seawater fish. Why is this so?

How much water needs to be excreted from the body is controlled by a process known as *osmoregulation*.

► **Osmoregulation** is the control of water potential and solute concentration (level) in the blood to maintain a constant water potential in the body.

The water potential of the blood in the body has to be kept relatively constant. This is because drastic changes in the water potential of the blood can result in serious problems. For example, if the blood plasma becomes too diluted, water will enter the blood cells by osmosis. The blood cells will swell and possibly burst. The tissue cells will also swell because water from the blood plasma will move into the cells.

On the other hand, if the blood plasma becomes too concentrated, water will move out of the cells by osmosis. The blood cells and tissue cells will become dehydrated and shrink. They will then not be able to carry out their metabolic functions properly. In severe cases, this may be fatal to the organism.

The water potential of the blood depends on the amount of water and mineral salts in the blood plasma. The amount of water in the blood plasma is controlled by **antidiuretic hormone (ADH)**. ADH is produced by a region of the brain called the **hypothalamus**. It is released by the **pituitary gland** and increases water reabsorption at the nephrons.

How Do Kidneys Help to Regulate the Water Potential of Blood?

The kidneys are called **osmoregulators** because they help to regulate the water potential and solute concentration in the blood. The regulation of water potential in the body is summarised in Figure 8.15.



Disciplinary Idea Homeostasis, Coordination and Response

Changes in the amount of water and solutes in the body above or below the normal level are detected. Through osmoregulation, the body will adjust to bring them back to the normal level, thus keeping the water potential of the body constant.



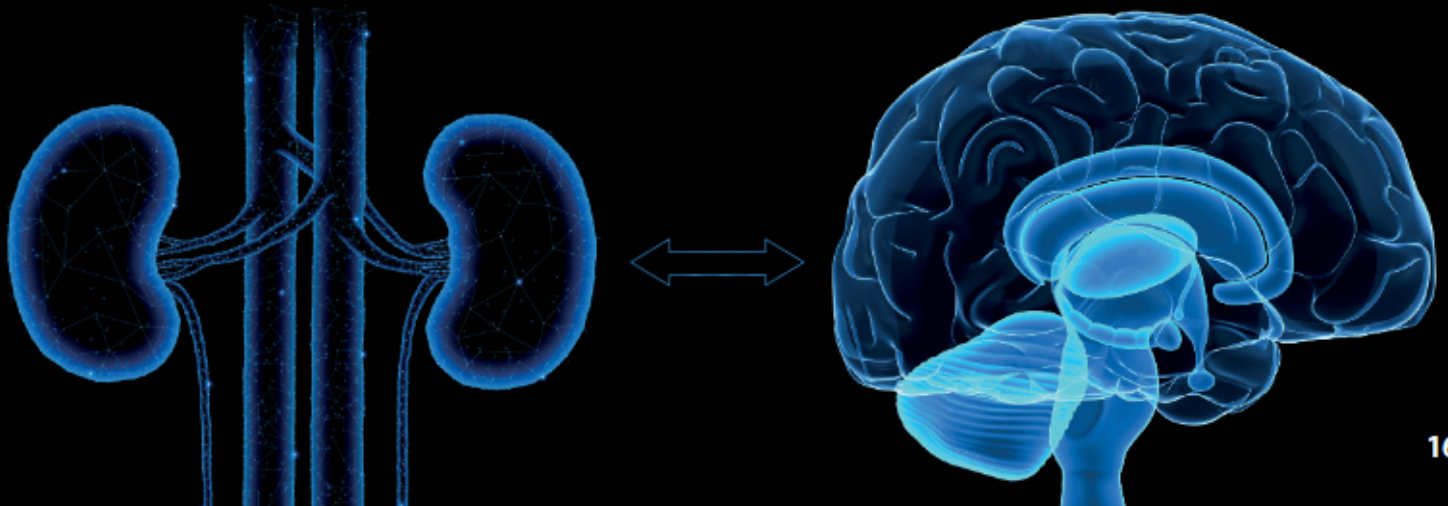
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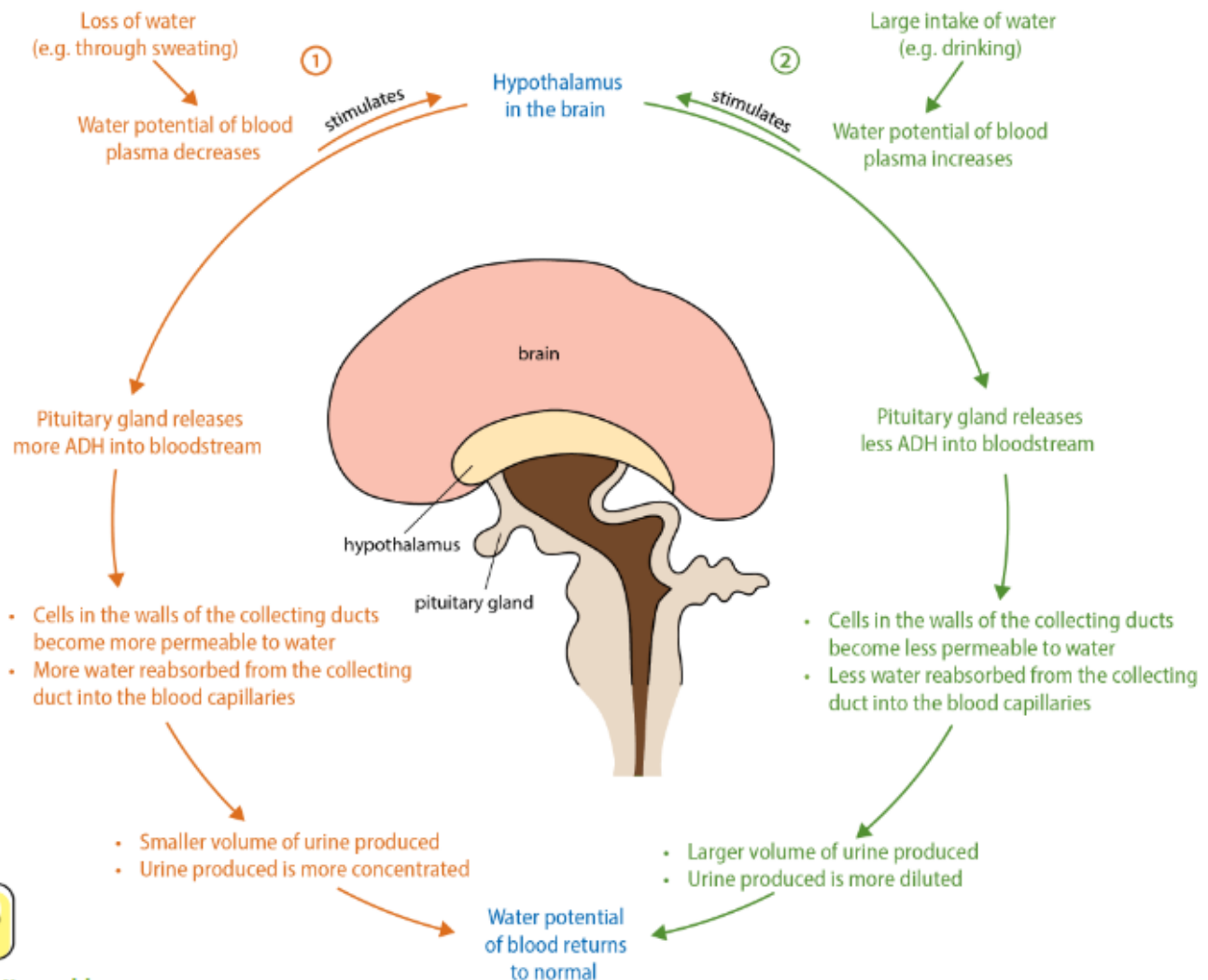
Osmoregulation is an example of homeostasis — the maintenance of a constant internal environment within an organism. Learn more about homeostasis and hormones in Chapter 9.



Word Alert

Antidiuretic: reducing urination





Disciplinary Idea

System

The kidneys work together with the brain and pituitary gland to ensure that the water potential of cells is maintained.



Link

Theory Workbook
Worksheet 8C

Figure 8.15 Osmoregulation in humans — how water potential of blood is kept constant when (1) there is loss of water and (2) there is a large intake of water

Let's Practise 8.4

- 1 Suggest how a large amount of salt in the diet leads to an increase in blood pressure.
- 2 Drinking too much alcohol is bad for your health. One unpleasant effect of drinking too much alcohol is having a hangover. Some of its symptoms are the results of dehydration rather than the direct effects of the alcohol itself. Alcohol causes dehydration, because it reduces the production of ADH.
 - (a) Why does the reduced production of ADH result in dehydration?
 - (b) Would the urine of a person with a hangover be dilute or concentrated?

8.5 What Happens When the Kidneys Fail?

Learning Outcome

- Outline the mechanism of dialysis in the case of kidney failure.

You may know someone who has to undergo dialysis every week, or someone who needs a kidney transplant. Most people who suffer from kidney failure depend on dialysis for the rest of their lives. This can be very costly.

Why Are the Kidneys Important?

- **The kidneys are excretory organs.**
They play an important role in excreting metabolic waste products, such as urea and excess water and mineral salts, in the form of urine.
- **The kidneys are osmoregulators.**
They regulate the solute concentration and water potential in the blood, thereby maintaining a constant water potential in the blood.



Link

Find out more about how the kidneys function as osmoregulators in Chapter 9.

What Causes the Kidneys to Fail?

Common causes of kidney failure include:

- high blood pressure
- diabetes
- alcohol abuse (constant heavy drinking)
- severe accidents that physically damage the kidney
- complications from undergoing major surgery

If one kidney fails to function, a person can still lead a normal life with the other kidney. However, if both kidneys fail to function, a person will die unless prompt medical treatment is given.

Patients with kidney failure may get a kidney transplant. A donor with two healthy kidneys may donate one kidney and survive with the remaining kidney. If a donor kidney is not available, the patient can be treated with **dialysis** using a **dialysis machine**. A dialysis machine mimics the functions of a kidney. It helps to clean the patient's blood from metabolic waste products and toxins.

In order for the treatment to be effective, the patient needs to undergo dialysis 2–3 times a week. Each dialysis session lasts about 3–5 hours, depending on the patient's body size and medical condition.



How Does a Dialysis Machine Work?

Figure 8.16 shows how a dialysis machine works.

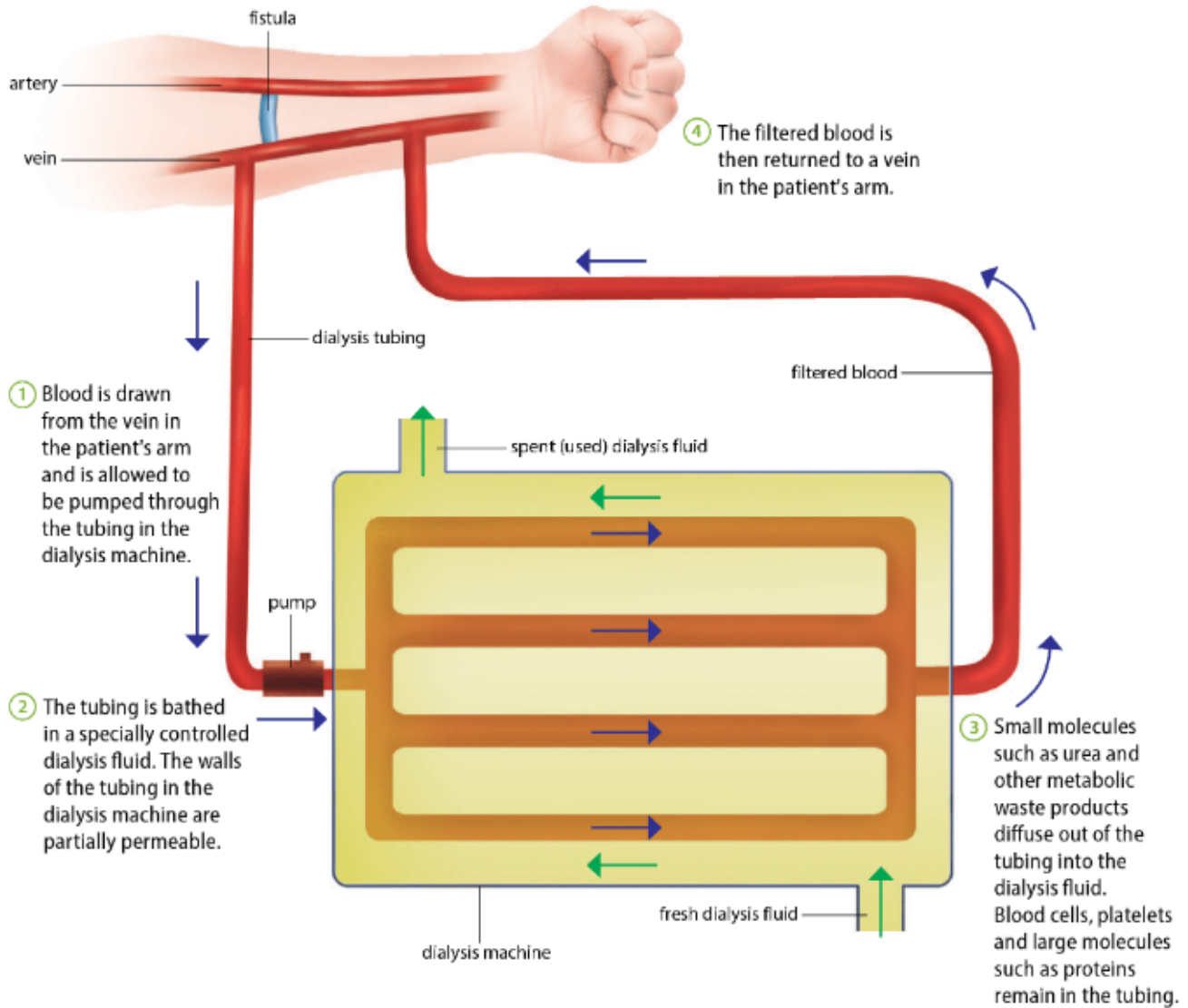


Figure 8.16 How a dialysis machine works



Helpful Note

A fistula is a direct connection of an artery to a vein. It is usually inserted into the forearm via a minor surgery. Blood pressure in the artery is higher than in the vein. As more blood at higher pressure flows into the vein, the vein becomes larger and stronger over time. Increased blood flow through the vein allows a greater amount of blood to pass through the dialysis machine. This allows filtration to occur at a pace that enables all the blood to be filtered in a shorter period of time.



Figure 8.17 Patient undergoing dialysis

What Are the Features of a Dialysis Machine?

- **The dialysis fluid contains the same concentration of essential substances as healthy blood.**
This ensures that essential substances (such as glucose, amino acids and mineral salts) do not diffuse out of the blood and into the dialysis fluid. Furthermore, if the patient's blood lacks these essential substances, these substances will diffuse from the dialysis fluid into the blood.
- **The dialysis fluid does not contain metabolic waste products.**
This sets up a concentration gradient that allows waste products, such as urea, and excess water and mineral salts, to diffuse out of the tubing into the dialysis fluid. The waste products are removed from the blood. This maintains the correct solute composition and water potential of the blood.
- **The tubing in the machine is narrow, long and coiled.**
This increases the surface area-to-volume ratio which helps to speed up the rate of exchange of substances between the patient's blood and the dialysis fluid.
- **The direction of the blood flow is opposite to the flow of the dialysis fluid.**
This maintains the concentration gradient for the removal of waste products (Figure 8.18).

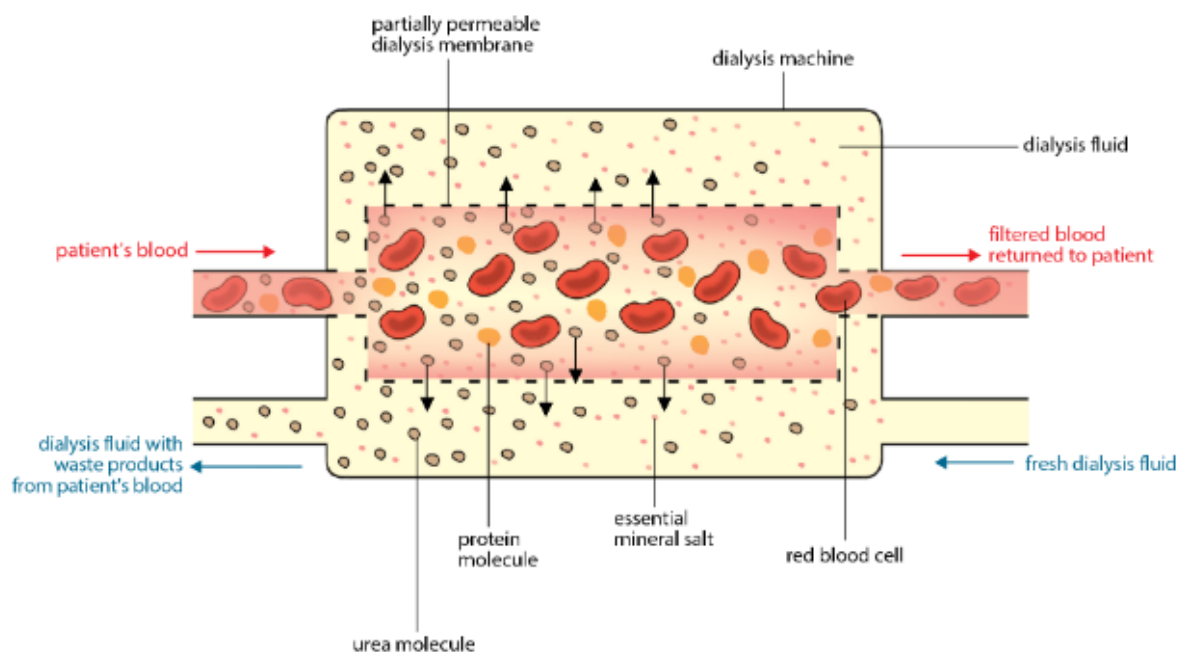


Figure 8.18 How substances are exchanged between the blood and the dialysis fluid in a dialysis machine



Tech Connect

Dialysis machines are bulky instruments that often require up to 8 litres of dialysis fluid for each use. Since patients who are suffering from kidney failure need to use the machine for several hours each day, they rarely travel overseas. With rapid advances in technology, scientists and engineers are trying to design smaller dialysis machines. This will make them portable and require far less amount of dialysis fluid to operate. While many of these 'artificial kidneys' are still being tested for safety and efficiency, perhaps the day will come when kidney failure patients can travel with confidence and convenience.



Figure 8.19 'Artificial kidneys' may be a possibility in the future.

Let's Practise 8.5

1 Figure 8.20 shows how a dialysis machine works.

- Name **two** substances that will pass from the blood into the dialysis fluid.
- By what process does each of the two substances named in (a) pass out of the tubing?
- Name a substance present in blood plasma that does not pass out of the tubing.
- What property must the wall of tubing X possess?

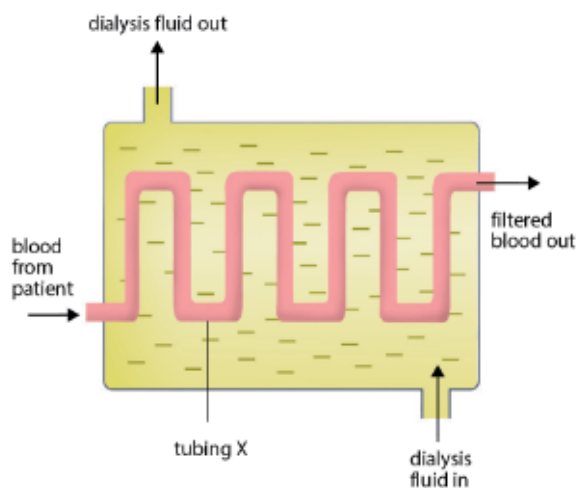


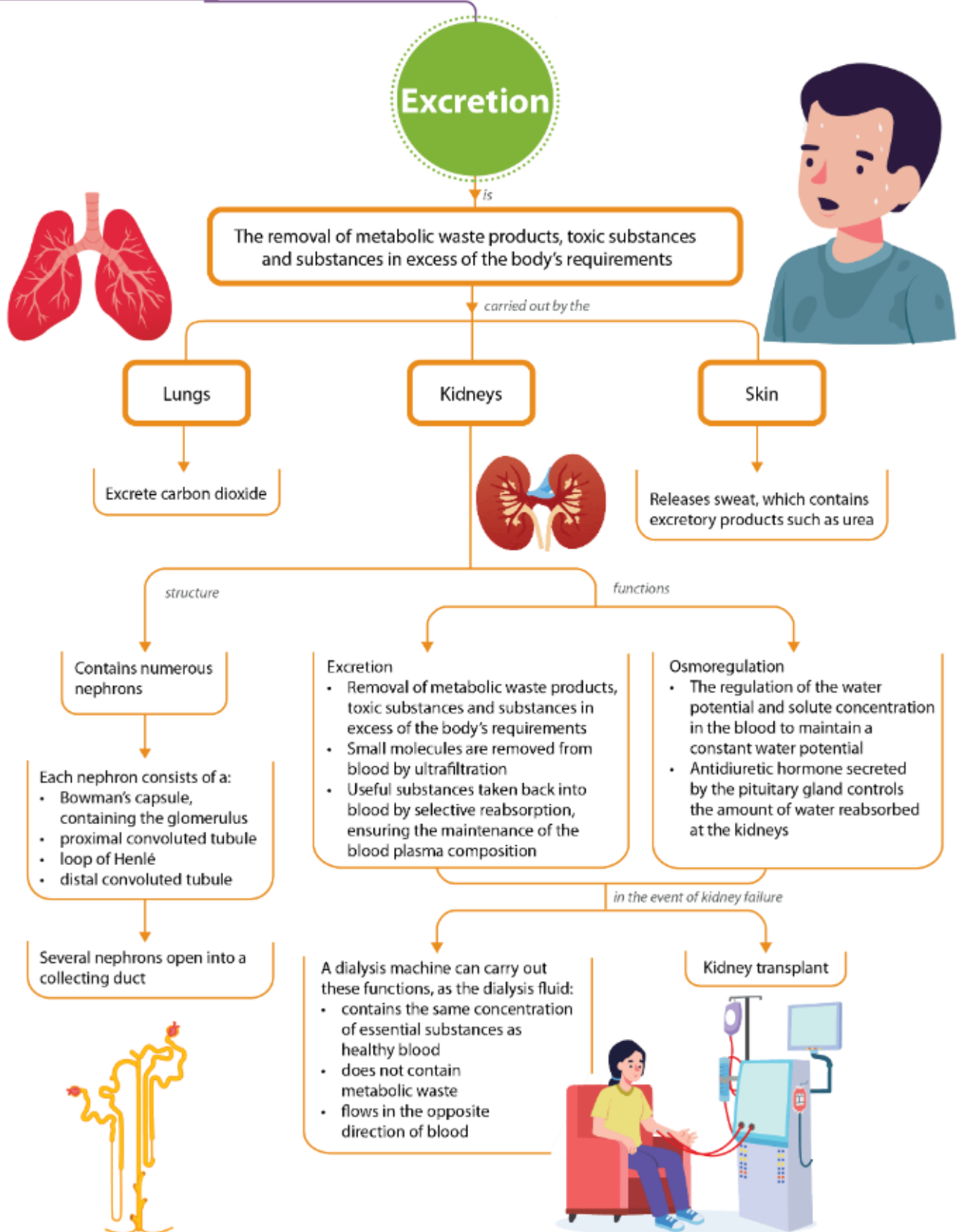
Figure 8.20



Link

Theory Workbook
Worksheet 8D
Let's Assess
Let's Reflect

Let's Map It



Let's Review

Section A: Multiple-choice Questions

- 1 Figure 8.21 shows a kidney of a healthy person with three tubes, X, Y and Z, attached. In which tube will urea be found?

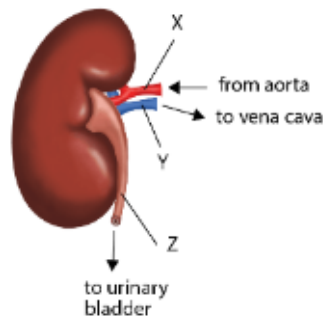


Figure 8.21

- ☐ A X only ☐ B X and Y only
☐ C X and Z only ☐ D X, Y and Z

- 2 What does blood in the renal artery contain compared with blood in the renal vein?

- ☐ A more carbon dioxide and less urea
☐ B less carbon dioxide and more urea
☐ C more oxygen and less urea
☐ D less oxygen and more urea

Section B: Structured Questions

- 1 (a) Name the excretory waste product formed from the breakdown of amino acids.
 (b) A person suffers from low blood pressure. How would this affect the process of ultrafiltration in his kidneys? What problems might result from this?
- 2 Three solutions, A, B, and C, are taken from three different regions of a human kidney. The three regions of the kidneys are as follows:
 Region 1: an arteriole coming from the renal artery
 Region 2: the first part of the nephron
 Region 3: the first part of the ureter as it leaves the kidney
 Biuret test and Benedict's test are carried out on each solution. Table 8.2 shows the results of the tests.

Table 8.2

Solution	Test	Observation	Deduction
A	Reducing sugar	Red precipitate	Reducing sugar present
	Protein	Solution remains blue	Protein absent
B	Reducing sugar	Red precipitate	Reducing sugar present
	Protein	Violet colouration	Protein present
C	Reducing sugar	Solution remains blue	Reducing sugar absent
	Protein	Solution remains blue	Protein absent

- (a) State which of the solutions, A, B or C, represents the fluid from each of the regions 1, 2, and 3.
 (b) Explain your answer in (a).
- 3 Answer the following questions on dialysis, as a treatment for kidney failure.
 (a) What would happen if the dialysis fluid did not contain essential salts?
 (b) (i) How is the surface area-to-volume ratio of the tubing in the dialysis machine increased?
 (ii) Why is it important to have a high surface area-to-volume ratio?
 (c) (i) Why is the direction of the flow of the dialysis fluid opposite to the flow of blood?
 (ii) What would happen if the direction of the flow of the dialysis fluid were the same as the direction of the flow of blood?

Section C: Free-response Questions

- 1 (a) Explain how the following conditions affect the volume of urine produced:
 (i) on a hot, windy day
 (ii) on a cold day
 (b) Suggest how urine volume will be affected if the blood pressure in the body falls.
- 2 Suggest why the removal of faeces from the body is not excretion.

CHAPTER

09

Homeostasis and Hormonal Control



What You Will Learn



- Why is homeostasis necessary?
- How do hormones control the human body?
- How does the body maintain a constant body temperature?

Have you noticed that some birds look puffier during the winter? How does this protect them against the winter cold? Do we have similar insulation mechanisms on our bodies? How are these mechanisms triggered?



9.1 Why Is Homeostasis Necessary?

Learning Outcomes

- Define *homeostasis* as the maintenance of a constant internal environment.
- Explain the basic principles of homeostasis in terms of stimulus resulting from a change in the internal environment, a corrective mechanism and negative feedback.
- Explain how blood glucose concentration is regulated by insulin and glucagon as a homeostatic mechanism.

Have you ever noticed an air conditioner automatically turning itself on when the temperature rises, and turning itself off when the temperature gets too cold? It is able to do that because it has a thermostat. The thermostat can detect if the surrounding temperature goes above or below the desired set temperature. Our bodies also have a similar mechanism to cool down when we get too hot and warm up when we get too cold.

What Is Homeostasis?

► **Homeostasis** is the maintenance of a constant internal environment.

The internal environment of the human body includes the blood and tissue fluids that surrounds the cells in the body. Homeostasis ensures that the conditions of the blood and tissue fluid in terms of temperature and water potential, for example, are kept within narrow limits.

By ensuring a relatively stable internal environment, homeostasis allows an organism to be independent from changes in the external environment (surroundings). The external environment is the environment in which an organism lives.

Examples of Homeostasis in Humans

Regulating Body Temperature

Why does body temperature have to be kept constant? The environmental conditions outside your body are continuously changing. Yet your body cells must be kept at a constant temperature. One of the reasons is because the enzymes in your body can only work within a certain range of temperatures. Changes in body temperature may result in enzyme inactivation or even denaturation. This explains why people suffering from high fever must consult a doctor, as high fevers can be fatal. You will study more about how the body regulates body temperature later in this chapter.

Regulating the Water Potential of Blood and Tissue Fluid

The composition of blood plasma and tissue fluid must be kept within very narrow limits to ensure that they are kept at a constant water potential. Drastic changes in the water potential will affect cells. If the water potential is higher than normal, this can cause cells to swell and burst. On the other hand, if the water potential is lower than normal, this can cause cells to crenate.



Link

Changes in the blood composition will affect the tissue fluid. This in turn will affect the cells of the body. Recall what you have learnt about the effects of different water potentials on cells in Chapter 3.

Regulating Blood Glucose Concentration

Why must blood glucose concentration be kept within narrow limits? Scattered within the pancreas are groups of gland cells called the islets of Langerhans. These islets secrete the hormones insulin and glucagon. These hormones are important in the regulation of blood glucose concentration in the body. Body cells need glucose for cellular respiration. Cellular respiration provides cells with energy to perform their vital activities. A drastic change in blood glucose concentration can thus be dangerous.

Blood normally contains about 70–90 mg of glucose per 100 cm³ of blood. Glucose levels in your blood rise after a sugary meal and fall during vigorous physical exercise or starvation. How does your body keep the concentration of glucose in your blood constant?

Figure 9.1 The human body temperature is usually kept constant at 37 °C. When you have a fever, your body temperature rises above 37.5 °C.



How Does Homeostasis Work?

If the water potential of your blood increases above the normal level, it is detected by a receptor (detector) in your body. Your body will respond by returning the water potential to the normal level. Similarly, if the water potential of your blood decreases below normal, your body will respond and cause the water potential to rise to the normal level again.

*In homeostatic control, your body reacts to bring about an opposite effect to the changes detected. If the system (your body) is disturbed, the disturbance sets in motion a sequence of events that tends to restore the system (your body) to its original state. This is the **negative feedback** process.*

There are organs or structures in your body that can detect changes in the body condition. These organs or structures are called **receptors** or **sense organs**. Any change from the normal condition is called the **stimulus**.



Disciplinary Idea

System

Components within the endocrine system work together to allow coordinated responses to internal and external stimuli.

Figure 9.2 shows the negative feedback process. For negative feedback to take place, there must be:

- a **normal level** or **set point** to be maintained
- a **stimulus**, which is a change in the internal environment
- a **receptor** that can detect the stimulus and send signals to the control centre
- a **corrective mechanism**, which brings about the reverse effect of the stimulus

Receptors detect that the set point is reached, causing the corrective mechanism to stop.

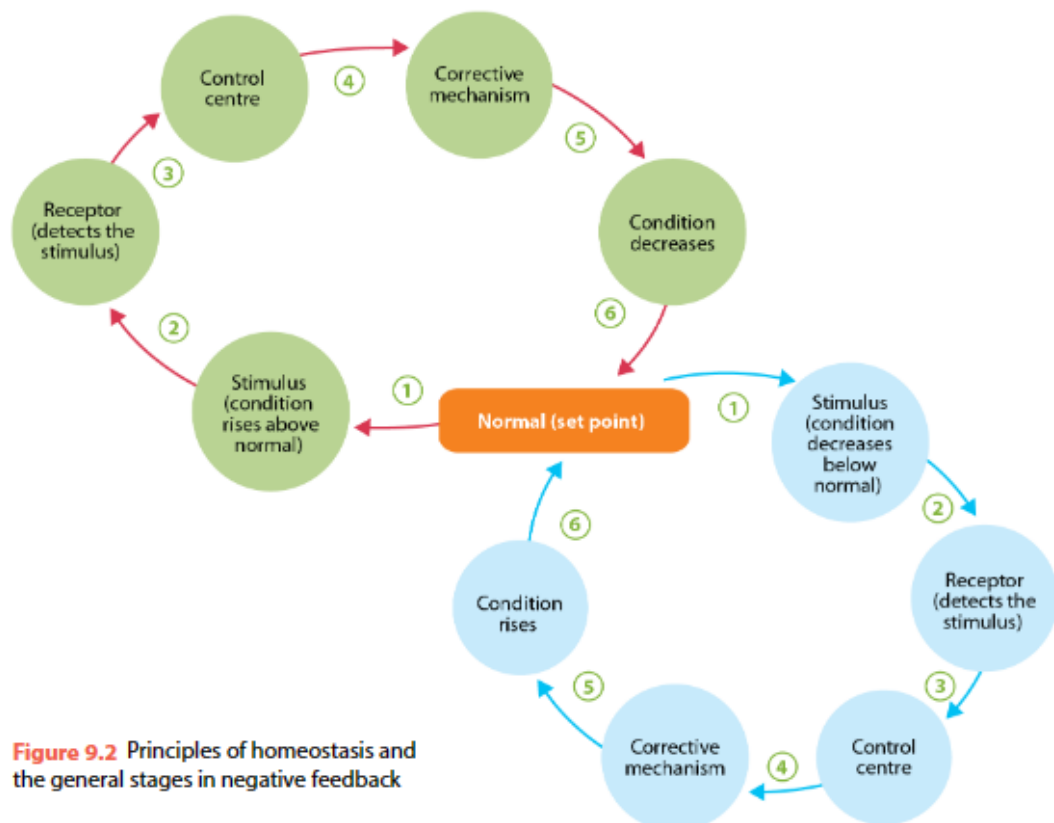


Figure 9.2 Principles of homeostasis and the general stages in negative feedback

Regulating Blood Water Potential

In Chapter 8, you have learnt how antidiuretic hormone (ADH) acts on the kidneys to help regulate the water potential of blood in the body through osmoregulation. ADH affects the reabsorption of water in the kidneys. Less ADH will lead to more urine production, while more ADH will lead to less urine production. Figure 9.3 summarises the homeostatic control of water potential in the blood.



Disciplinary Idea

Homeostasis, Coordination and Response

Changes in the amount of water and solutes in the body above or below the normal level are detected. Through osmoregulation, the body will adjust to bring them back to the normal level, thus keeping the water potential of the body constant.



Link

Recall what you have learnt in Chapter 8 about the role of antidiuretic hormone in osmoregulation.

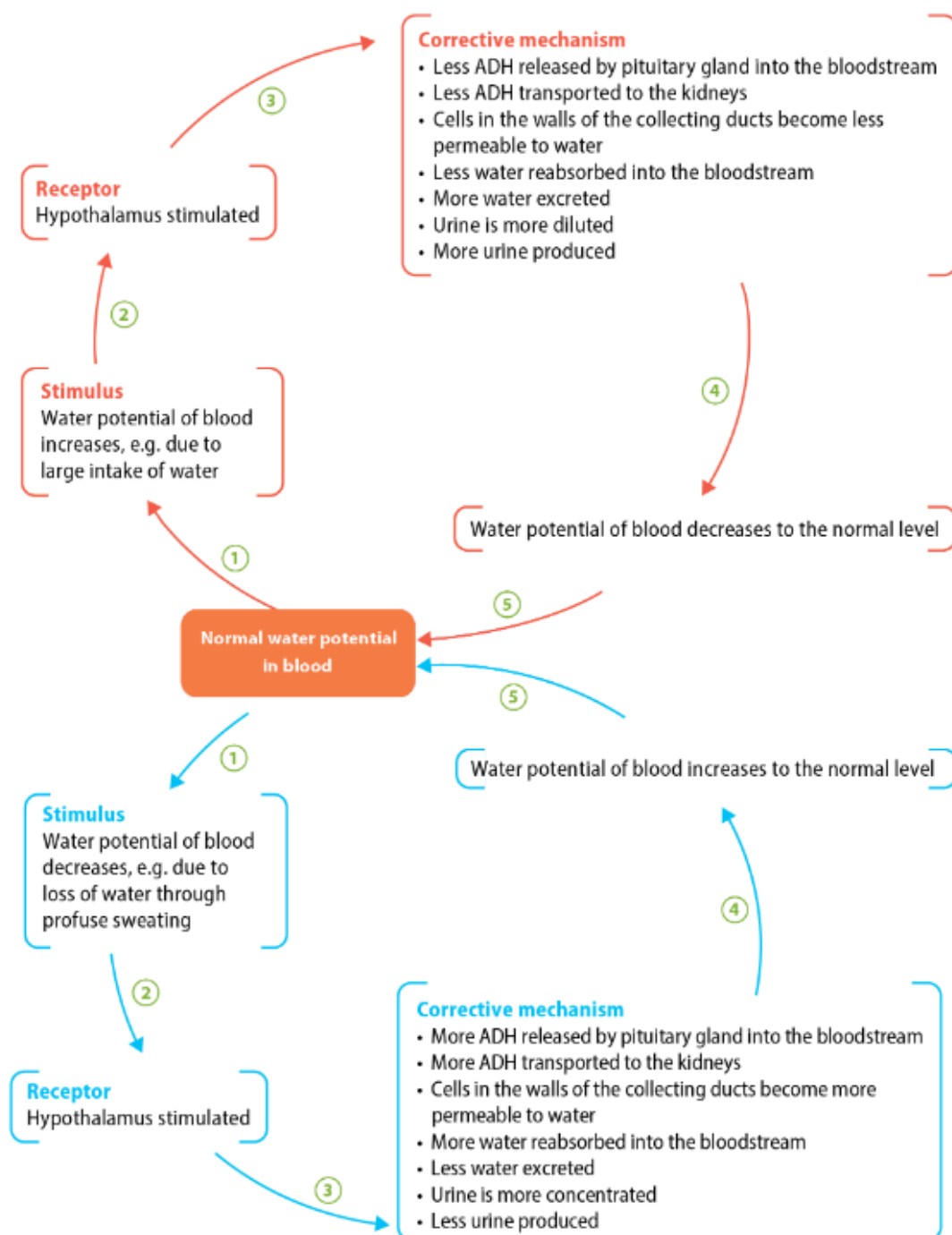


Figure 9.3 Homeostatic control of water potential in humans



Cool Career

Sports Physiologist

Sports physiologists apply knowledge of science to help athletes perform better. To do this, they need to have a firm understanding of homeostasis, especially in the regulation of body temperature, blood sugar, and osmoregulation.

How does knowledge in homeostasis help sports physiologists better understand how an athlete performs during exercise?



Figure 9.4 Sports physiologists conducting a performance test on an athlete



Link

Theory Workbook
Worksheet 9A

Let's Practise 9.1

- 1 Name the process by which the body maintains a constant internal environment.
- 2 Explain the homeostatic control of blood glucose concentration.

9.2 How Do Hormones Control the Human Body?

Learning Outcomes

- Define a hormone as a chemical substance, produced by a gland, carried by the blood, which alters the activity of one or more specific target organs.
- Explain what is meant by an endocrine gland, with reference to the islets of Langerhans in the pancreas.
- Describe type 2 *diabetes mellitus* in terms of a persistently higher than normal blood glucose concentration due to the body's resistance to insulin or insufficient production of insulin.
- Identify the risk factors of (e.g. unhealthy diet and sedentary lifestyle) and ways to manage type 2 *diabetes mellitus*.

You may have watched movies where spies send secret signals to each other. For example, if spy A scratches his head, it is a signal for spy B to make a move. If spy A scratches his nose, it means spy B should wait. These signals or messages are only intended for and understood by spy B. They are not understood and therefore ignored by others. This scenario is much like how the body tells various organs what to do — using hormones as a chemical message to be read and understood by the specific organs.

What Is a Hormone?

► A **hormone** is a chemical substance produced in minute quantities by an endocrine gland. It is transported in the bloodstream to target organ(s) where it exerts its effect(s).

Hormones can influence the growth, development and activity of an organism. They are chemical messengers that help the various parts of the body to respond, develop and work together smoothly.

Since hormones help to control and coordinate body activities, their production must be carefully controlled to prevent disastrous results. For example, a person will suffer from diabetes if too little of the hormone insulin (Figure 9.5) is produced in the body. Signs of diabetes include fatigue, weight loss, high blood glucose level and slow healing of wounds.

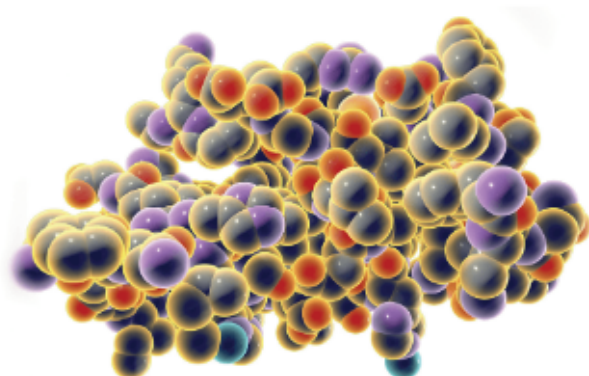


Figure 9.5 Molecular model of the hormone insulin

Where Are Hormones Produced?

Hormones are produced by glands. All the glands you have read about so far have a duct or tube for carrying away their secretions. For example, the salivary gland has a salivary duct to carry saliva to the mouth. The sweat gland has a duct for carrying sweat out of the body. Such glands are called **exocrine glands** (Greek: *exo* = outwards).

However, hormones are produced by **ductless glands**. As the name implies, a ductless gland does not have a duct to carry away its secretion. The hormone produced by a ductless gland is secreted directly into the bloodstream. The bloodstream then distributes the hormone around the body. Ductless glands are known as **endocrine glands** (Greek: *endo* = within).

Some glands are purely endocrine glands, producing only hormones, e.g. the pituitary gland that secretes ADH. Other glands such as the pancreas produce both hormones and other secretions:

- The pancreas produces pancreatic juice, which is carried by the pancreatic duct to the duodenum.
- The pancreas also contains special groups of cells known as the **Islets of Langerhans** which secrete the hormones **insulin** and **glucagon** into the bloodstream.

Hence, the pancreas can be considered both an endocrine and exocrine gland.



Link

Pancreatic juice contains various enzymes that are important for chemical digestion. Recall what you have learnt in Chapter 5.



Endocrine Glands and Their Hormonal Secretions

The relative positions and short descriptions of some endocrine glands are shown in Figure 9.6.

Pituitary gland
It plays an important role as a 'controller'. It secretes a number of hormones, which control the secretion of hormones of several other endocrine glands. This is why the pituitary gland is often referred to as the 'master gland'. The pituitary gland also secretes the antidiuretic hormone (ADH).

Hypothalamus
It is an endocrine gland that regulates the secretion of some hormones.



Helpful Note

Some glands such as the gonads (ovaries or testes) do not function until a person reaches puberty.

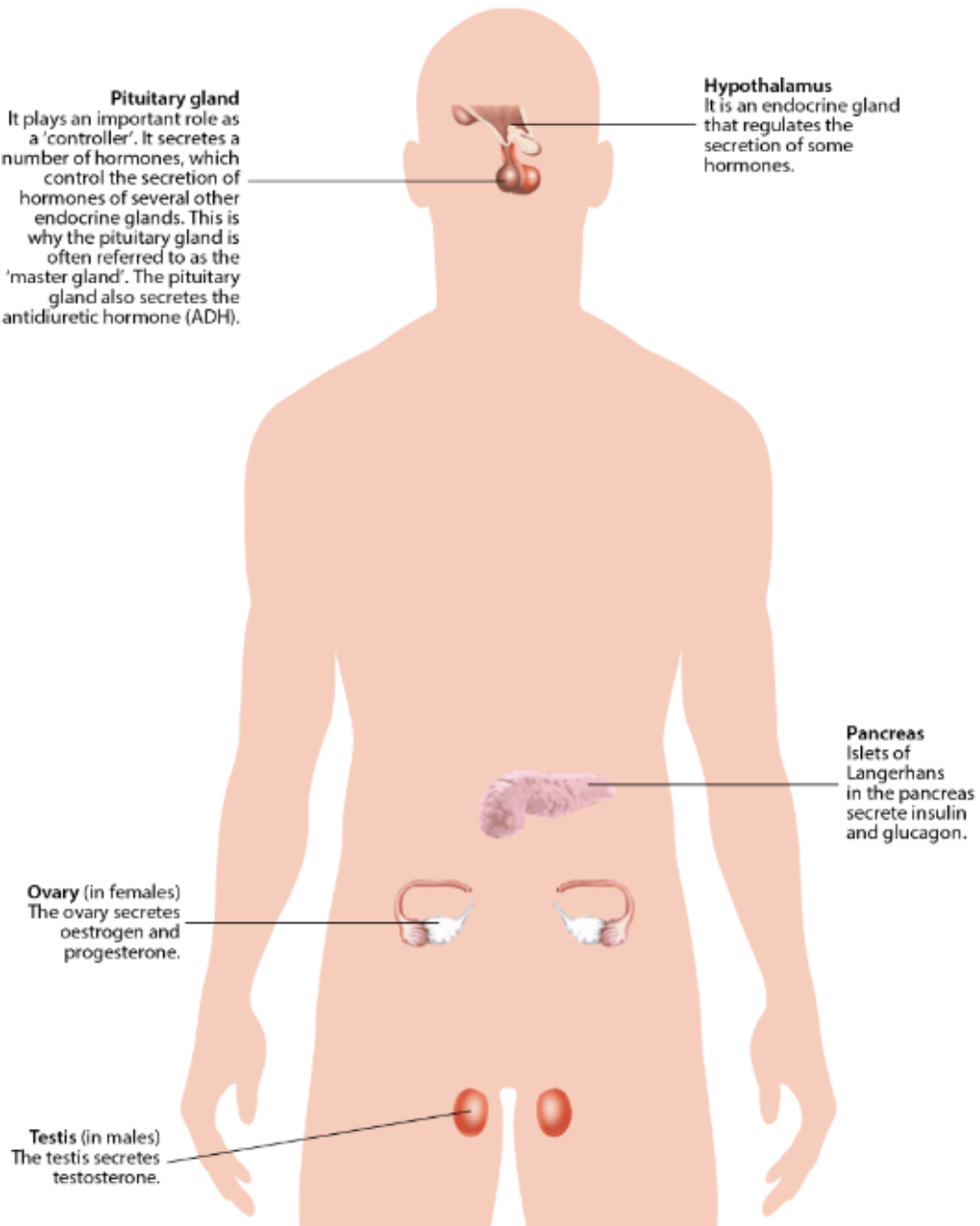


Figure 9.6 Location of some endocrine glands

Let us take a closer look at the effects of the hormones, insulin and glucagon, which are secreted by the islets of Langerhans in the pancreas.



Effects of Insulin

The islets of Langerhans in the pancreas increase the secretion of the hormone insulin when the concentration of blood glucose increases above normal levels. Insulin promotes the utilisation of glucose by the cells. Table 9.1 shows the effects of insulin on the body.

Table 9.1 The effects of insulin on the body

Amount of Insulin Secreted	Effect
Normal	- Decreases blood glucose concentration by: - making cell membranes more permeable to glucose, allowing more glucose to diffuse into the liver and muscle cells - stimulating the liver and muscle cells to convert excess glucose into glycogen for storage - increasing the use of glucose for respiration
Lack of secretion	- Increases blood glucose concentration as: - glucose cannot be stored or utilised by tissue cells (Hence, blood glucose concentration rises. Some glucose is subsequently lost in the urine. This gives rise to a disease called diabetes mellitus.) - Muscle cells have no reserves of glycogen, the body grows weak and continuously loses weight
Oversecretion	- Abnormal decrease in blood glucose concentration such that: - low blood glucose concentration results in a condition called <i>shock</i> - seizures or fits, collapsing or passing out may follow

Effects of Glucagon

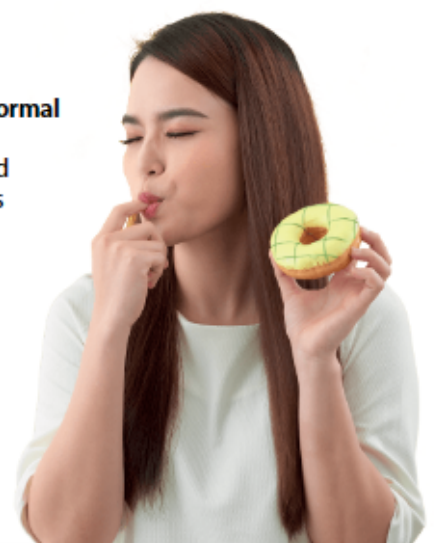
The islets of Langerhans increase the secretion of the hormone glucagon when the concentration of blood glucose decreases below normal levels. The main target of glucagon is the liver. Glucagon increases blood glucose concentration by stimulating:

- the conversion of glycogen into glucose
- the conversion of fats and amino acids into glucose

Insulin and glucagon together regulate the blood glucose concentration. This is an example of a *homeostatic mechanism*.

What Happens When Blood Glucose Concentration Rises Above the Normal Level?

After meals, especially those rich in carbohydrates, glucose is absorbed into the bloodstream in the small intestine. When this happens, events take place in the body to maintain the blood glucose concentration (Figure 9.7 on the next page).



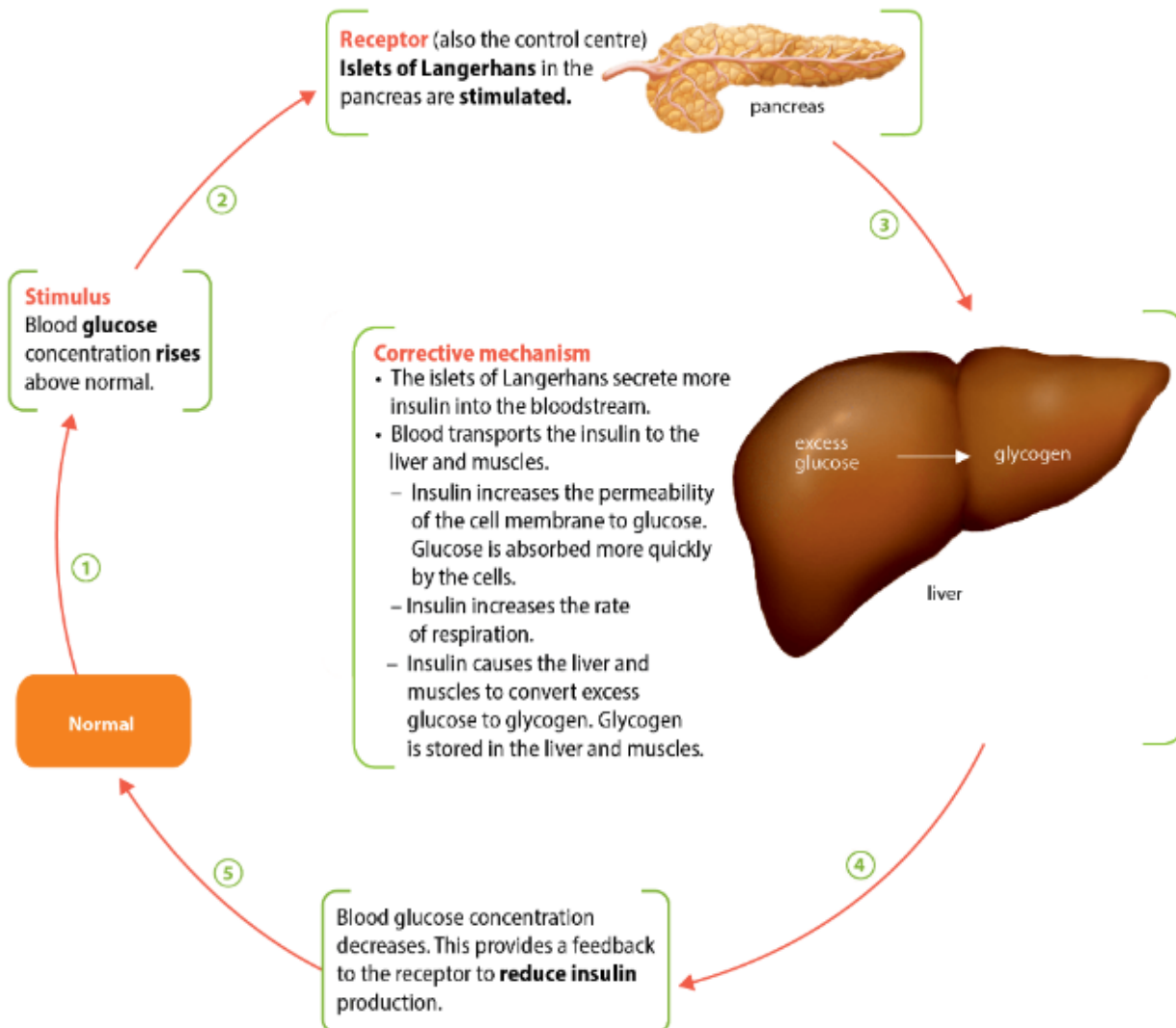


Figure 9.7 Homeostatic control of blood glucose concentration when blood glucose concentration rises above normal level

What Happens When Blood Glucose Concentration Falls Below the Normal Level?

During vigorous muscular contractions or during starvation, glucose is used up for respiration to provide energy. The glucose level in the blood drops. When this happens, events take place in the body to maintain the blood glucose concentration (Figure 9.8).



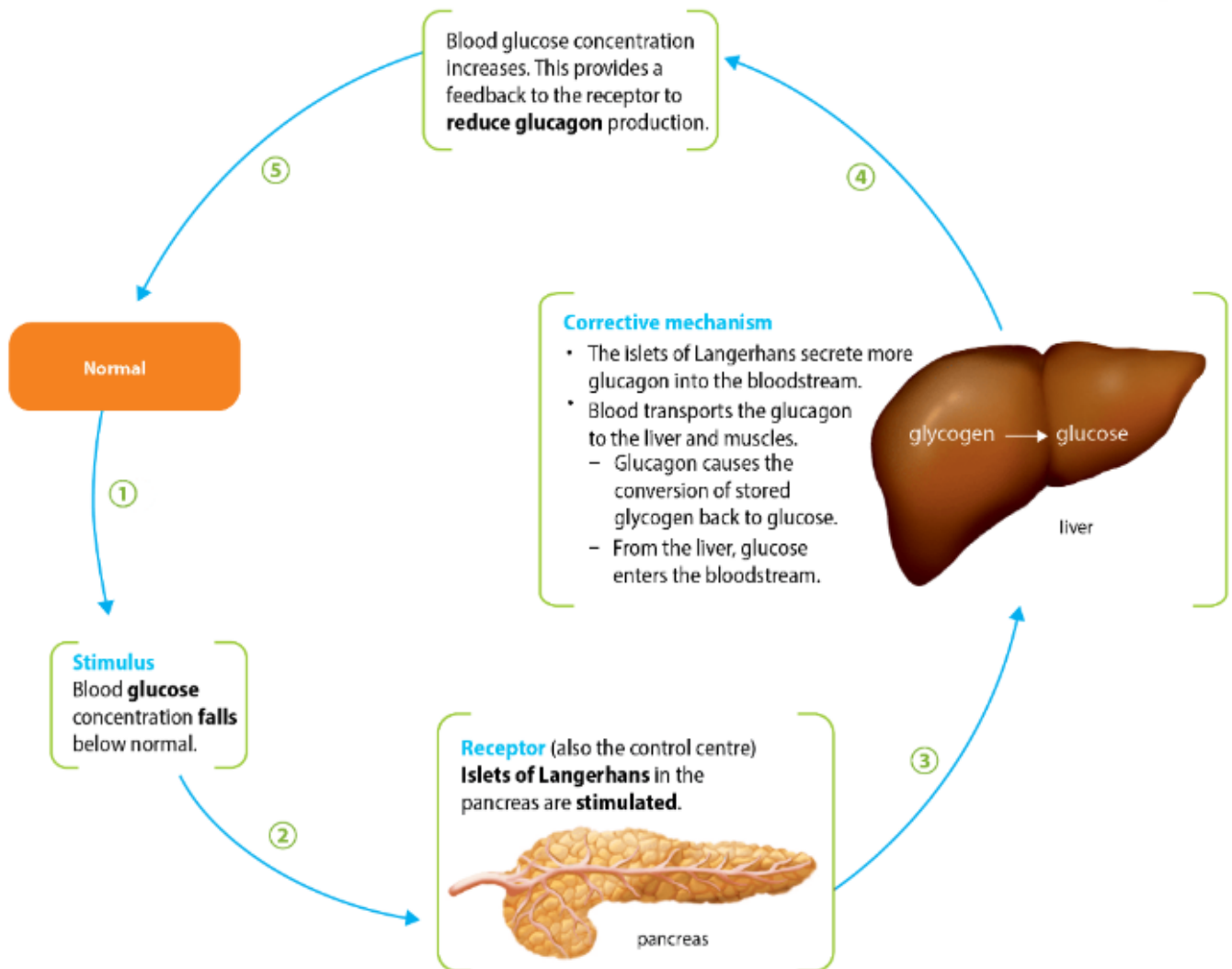


Figure 9.8 Homeostatic control of blood glucose concentration when blood glucose concentration falls below normal level

What Is Diabetes Mellitus?

Diabetes mellitus or diabetes is a disease in which the body is unable to control its blood glucose concentration in order for it to remain within normal limits. As a result, the blood glucose concentration can rise to a level that exceeds the kidney's ability to completely reabsorb all the glucose. The glucose that is not reabsorbed is excreted in the urine.

There are two main types of diabetes: *type 1* and *type 2*.

- **Type 1 diabetes** develops early in a person's life. Hence, it is known as *juvenile* or *early-onset diabetes*. In type 1 diabetes, the islets of Langerhans are unable to produce or secrete sufficient insulin. It is inherited.
- **Type 2 diabetes** occurs later in a person's life and hence is called *late-onset diabetes*. Overweight people are more likely to develop type 2 diabetes. Type 2 diabetes develops when the target cells, such as the muscle cells, do not respond well to insulin.

The signs and symptoms of diabetes include the following:

- a persistently high blood glucose level
- the presence of glucose in the urine
- healing of wounds is slow or difficult
- frequent urination
- weight loss
- thirst





Word Alert

Diabetics: people with diabetes

How Can Diabetes Be Treated?

Diabetics have to measure their blood glucose concentrations and test their urine regularly. They must also watch their diet carefully, making sure that they do not take in too much carbohydrates.

People with type 1 diabetes have to inject insulin regularly into the fat tissue under the skin, e.g. into the abdomen. If they use too much insulin, exercise too much or eat too little, their blood glucose can drop too low. In severe cases, low blood glucose concentration may cause them to go into a coma. Hence, they need to always be ready with a supply of sugary food such as glucose sweets. Diabetics should also take medication that increases the uptake of glucose from the bloodstream into cells.

If you are a couch potato, you run the risk of getting type 2 diabetes. What causes this disease? What lifestyle should a person lead to reduce the risk of getting the disease?

What Are the Risk Factors of Type 2 Diabetes?

In type 2 diabetes, the liver and muscle cells do not respond well to insulin. This is called **insulin resistance**. They are unable to take in excess glucose in the blood. Hence, the blood glucose level remains high. Type 2 diabetes is more common in older adults. However, the increase in the number of younger people with obesity has led to an increase in type 2 diabetes in younger people. Figure 9.9 shows some risk factors for type 2 diabetes.

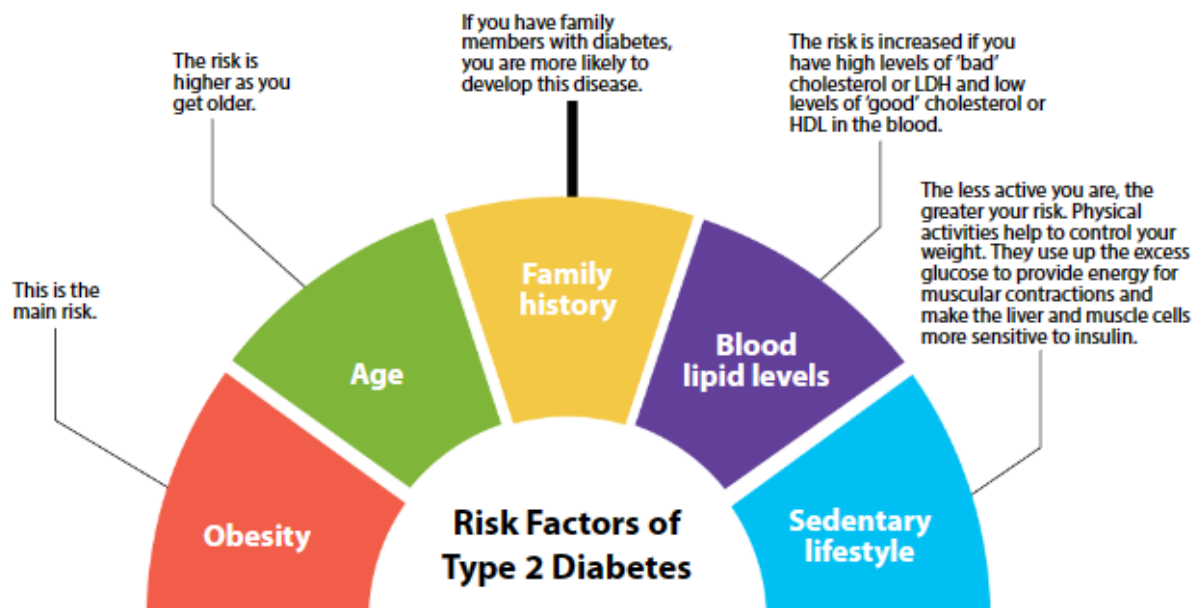


Figure 9.9 Factors that may increase the risk of type 2 diabetes

A healthy lifestyle can reduce the risk of getting type 2 diabetes.

This includes the following:

- Eat healthily: consume foods that are low in calories and high in fibre, e.g. eat more fruit and vegetables.
- Engage in more active physical activities.
- Avoid being inactive for long periods of time, e.g. sitting for too long.
- Maintain a healthy body weight, based on your age and height.

Type 2 diabetes usually develops over a long period of time. It is important that we are well-informed about this disease. What are some common misconceptions that people may have about diabetes? Why do you think the opinion of each person in Figure 9.10 is a misconception?

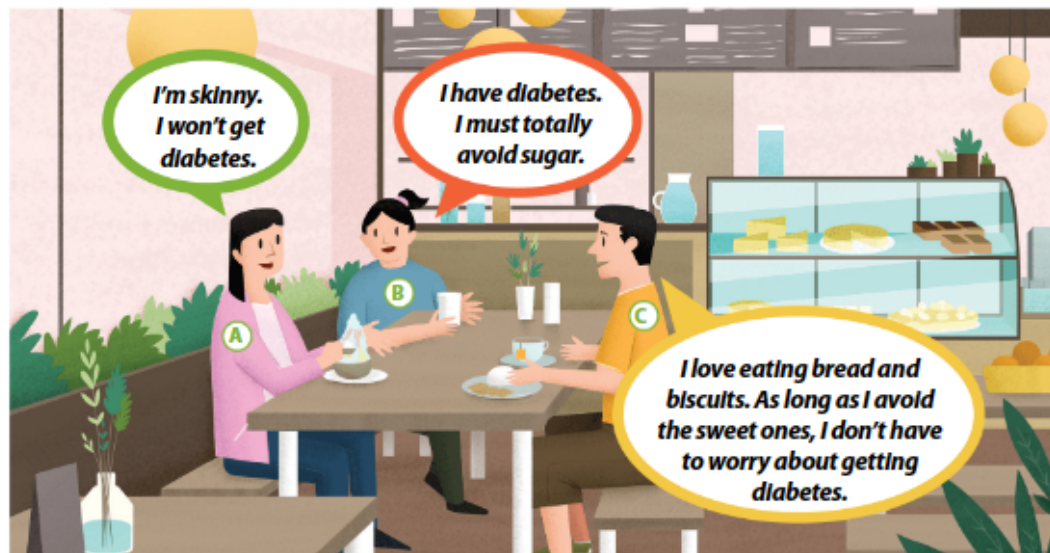


Figure 9.10 The three friends have some opinions about diabetes. Why do you think these are misconceptions?



Tech Connect

Scientists and engineers have developed a sensor that can be worn on the back of the upper arm to measure the blood glucose level in the wearer. A reading device is used to scan over the sensor to get a reading of the glucose level in the body. This device can be used to monitor the patient's glucose patterns and trends (Figure 9.11).

Another type of sensor can be worn under the skin at the abdomen. It sends information to a smart phone app that continuously monitors the blood glucose level of the wearer.

Diabetics no longer need to prick their fingers to check their blood glucose level.



Figure 9.11 Scanning device used to read blood glucose level in the body

Let's Practise 9.2

- 1 Define a **hormone**.
- 2 What is an endocrine gland?
- 3 (a) Name **two** hormones produced by the pancreas.
(b) Name the gland in the pancreas that produces the two hormones.
(c) Draw and label the gland in (b) on the diagram in Figure 9.12.
- 4 (a) Name the disease caused by a failure of the pancreas to produce insulin.
(b) State **two** possible signs and symptoms of the disease named in (a).
(c) How can the disease be treated?
- 5 State **two** factors that increase the risk of type 2 diabetes.

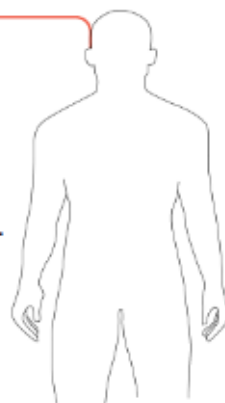


Figure 9.12



Link

Theory Workbook
Worksheet 9B

9.3 How Does the Body Maintain a Constant Body Temperature?

Learning Outcome

- Describe the maintenance of a constant body temperature in humans in terms of the role of: temperature receptors in the skin detecting changes in temperature, sweating, shivering, altering blood flow through blood vessels near the skin surface, and the coordinating role of the hypothalamus.

Have you ever shivered when you take a cold shower? Have you noticed your friend sweating and his skin turning red when the weather is very hot or when he is running? These are all part of your body's varied ways of regulating internal temperature by either preventing heat loss, generating heat or increasing heat loss.

Structures in the Skin Involved in Temperature Regulation

The skin forms a protective covering over the body surface. It also plays a role in the regulation of body temperature and excretion. How does the skin perform these functions? Figure 9.13 shows a vertical section of the skin.

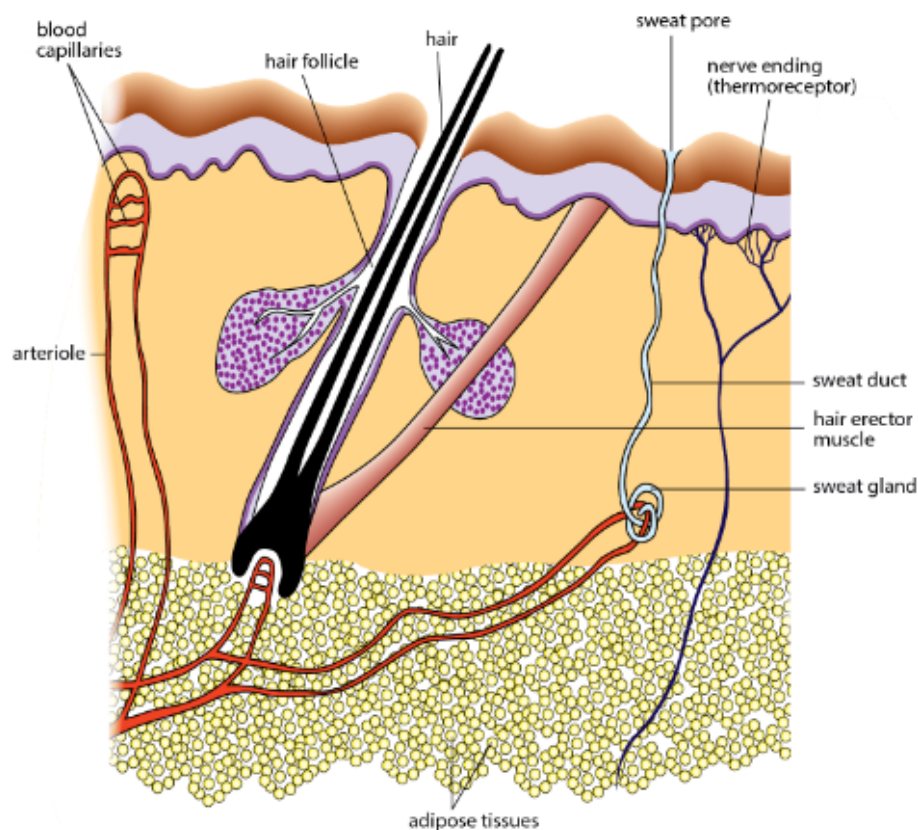


Figure 9.13 Section of the human skin

Blood Vessels (Capillaries and Arterioles) Under the Skin Surface

Blood vessels are present under the skin surface (Figure 9.13). The **constriction** and **dilation** of arterioles are caused by the contraction and relaxation of muscles in the arteriole walls. The contraction and dilation of the arterioles help to regulate body temperature.

Dilation of the arterioles is called **vasodilation**. When the skin arterioles dilate, more blood is sent to blood capillaries in the skin. This is shown when we blush or become flushed after vigorous activities. The skin turns red because the numerous blood vessels in the skin dilate.

The constriction of the arterioles in the skin, or **vasoconstriction**, reduces the amount of blood flowing through the capillaries in the skin and causes us to become pale.

Sweat Glands

Secreted sweat flows through a **sweat duct** to a **sweat pore** that opens at the skin surface. Secreted sweat is mainly made up of water and it contains dissolved salts (mainly sodium chloride) and small amounts of urea. Since sweat contains small amounts of metabolic waste products, such as urea, the skin is considered an excretory organ.

Sweat is secreted continuously. The amount of sweat produced varies on the external and internal environmental conditions. Sweat produced in very small quantities evaporate almost immediately whereas sweat produced in large quantities appears as droplets on your skin or as 'running streaks' of liquid. *Sweat is a means by which your skin regulates body temperature.*



Word Alert

Constriction: narrowing, closing up
Dilation: broadening, opening up



Helpful Note

'Vaso' means related to the blood vessels. Vasodilation and vasoconstriction cannot be used to describe capillaries as there are no muscles in the one-cell thick capillary wall.



Helpful Note

The primary function of sweat is to remove excess heat from your body. Excretion of metabolic waste occurs primarily via the kidneys, and *not* the skin.





Sensory Receptors

The structures in the body that detect changes in the environment (i.e. stimuli) are called **sensory receptors** or sense organs. The nerve endings in the skin are sensory receptors (Figure 9.14). They enable you to sense pain, pressure and temperature changes in the external environment. Receptors that detect temperature changes are called **thermoreceptors**.

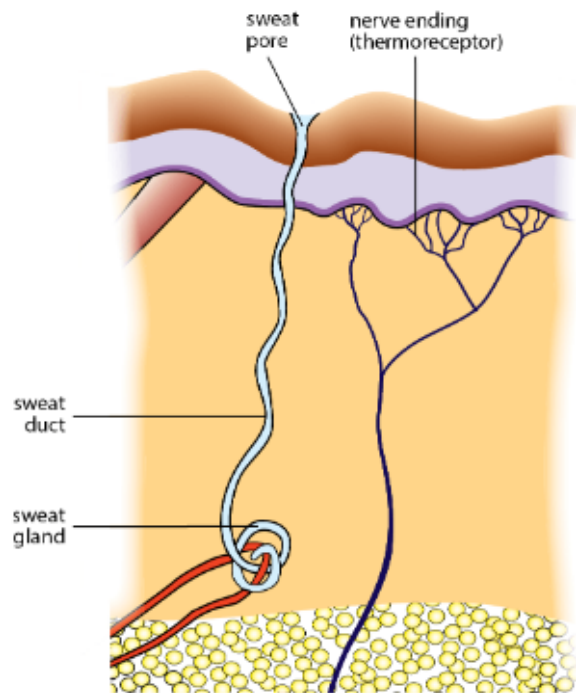


Figure 9.14 Section of skin showing a sweat gland and a sensory receptor

How Does the Body Gain and Lose Heat?

Heat is released in your body and lost from your body all the time. Your body needs to balance heat release and heat loss to maintain a constant internal temperature.

Heat Gained by the Body

Heat is released within the body as a result of metabolic activities such as cellular respiration. High levels of cellular respiration take place in the muscles and liver. Thus, a large amount of heat is released in these organs. The heat is distributed to the rest of the body via the bloodstream.

The body can also gain extra heat through:

- vigorous muscular exercise
- the consumption of hot food
- being in warm environments (e.g. being outdoors on a very hot day)

Excess heat needs to be removed from the body. If not, one could die of overheating.

Heat Lost by the Body

Heat is lost:

- through the skin
- by evaporation of water in sweat from the surface of the skin
- in the faeces and urine
- in the air that is exhaled

The amount of blood flowing through the skin capillaries affects heat loss through the skin surface (Figure 9.15).

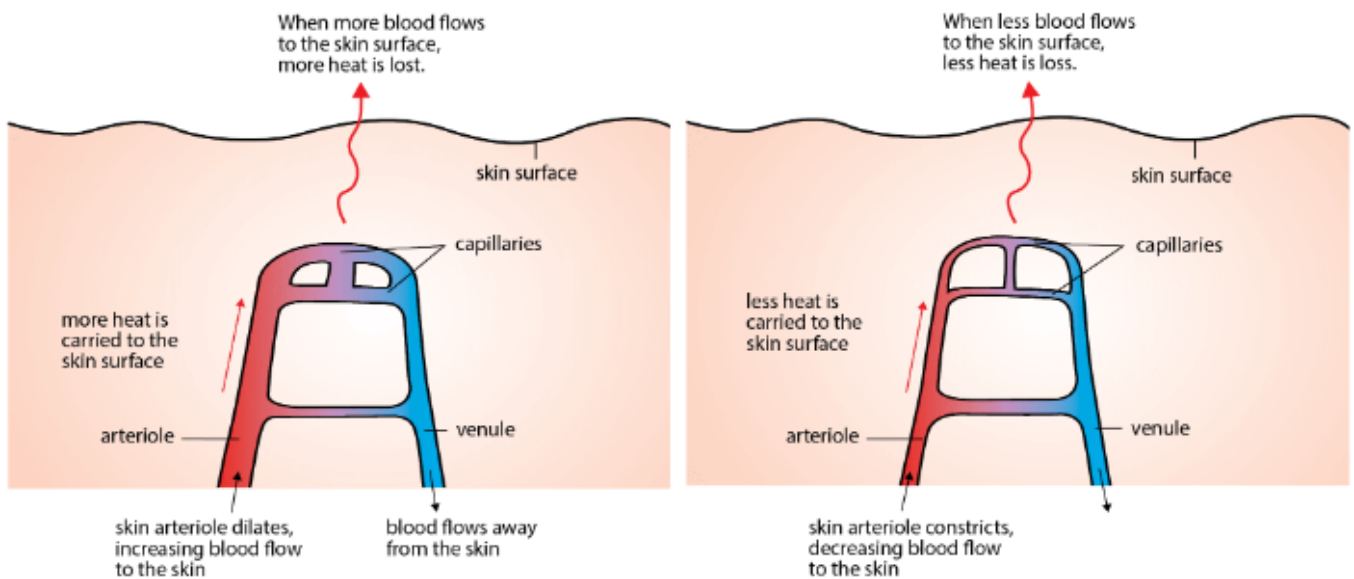


Figure 9.15 The effect of blood vessel constriction and dilation



Certain parts of the skin contain shunt vessels, which connect the skin arterioles with the skin venules. They control the amount of blood flowing through the skin.

Helpful Note

When the shunt vessels constrict, the skin arterioles dilate. When the shunt vessels dilate, the skin arterioles constrict.

How Is Body Temperature Regulated?

The **hypothalamus** in the brain monitors and regulates the body temperature. It receives information about temperature changes from two sources — thermoreceptors in the skin which detect temperature from the environment and thermoreceptors in the hypothalamus which detect temperature of the blood.

What Happens When the Body Temperature Begins to Rise?

On a warm day, the rate of heat loss from the body decreases. When we perform vigorous muscular activities, the large amount of heat released internally accumulates in the body. This causes a rise in the blood temperature. The hypothalamus detects this rise. It sends out nerve impulses to the relevant parts of the body to bring about certain changes within the body (Figure 9.16). These changes will cause a decrease in the body temperature.



Link

Physics

Infrared radiation is responsible for the sensation of heat we feel when we are near something hot.

Our body also absorbs heat when the surrounding temperature is higher than our body temperature, e.g. on a warm day. The thermoreceptors in the skin detect the rise in the external temperature and immediately send nerve impulses to the hypothalamus (Figure 9.16). The absorbed heat is mainly lost by the evaporation of sweat from the body.

Thus, the temperature of the body is kept constant. The extra heat released during vigorous muscular activity or the extra heat absorbed when in warm environments is removed so that the body temperature is maintained within a normal range.

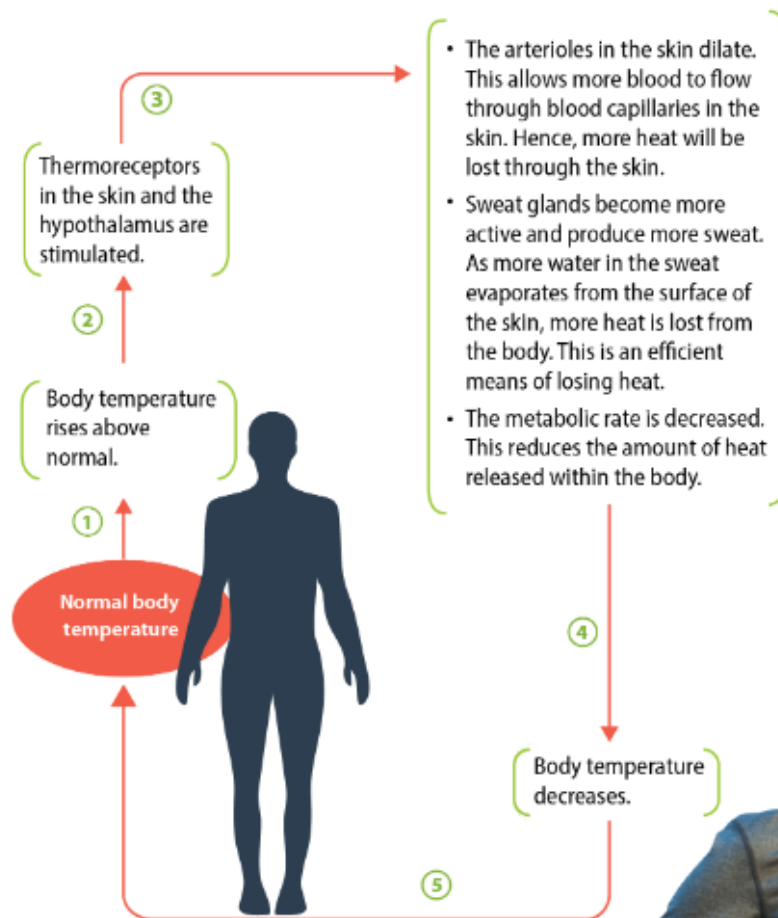
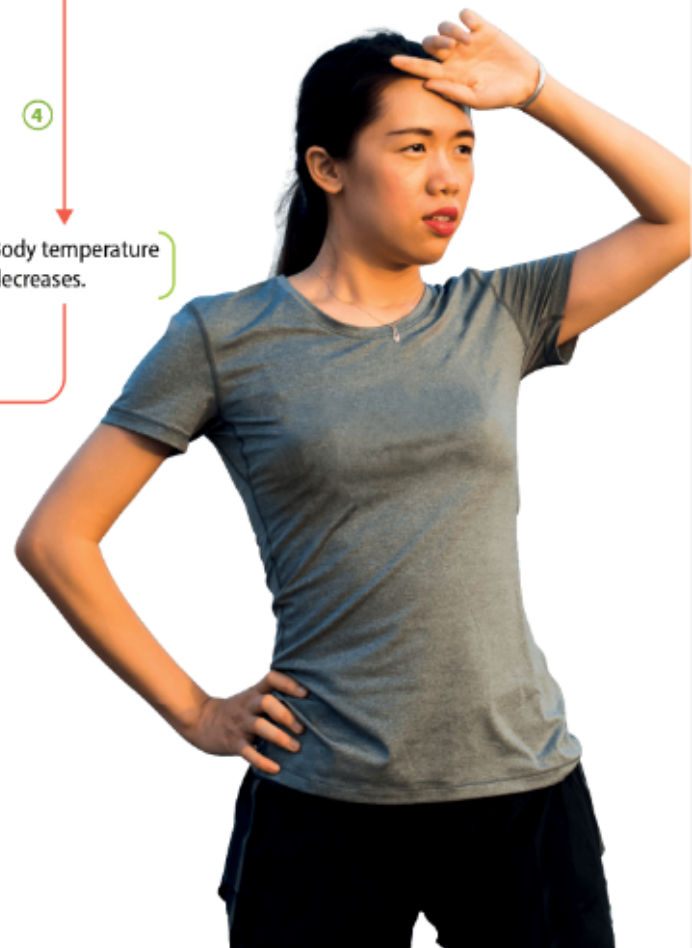
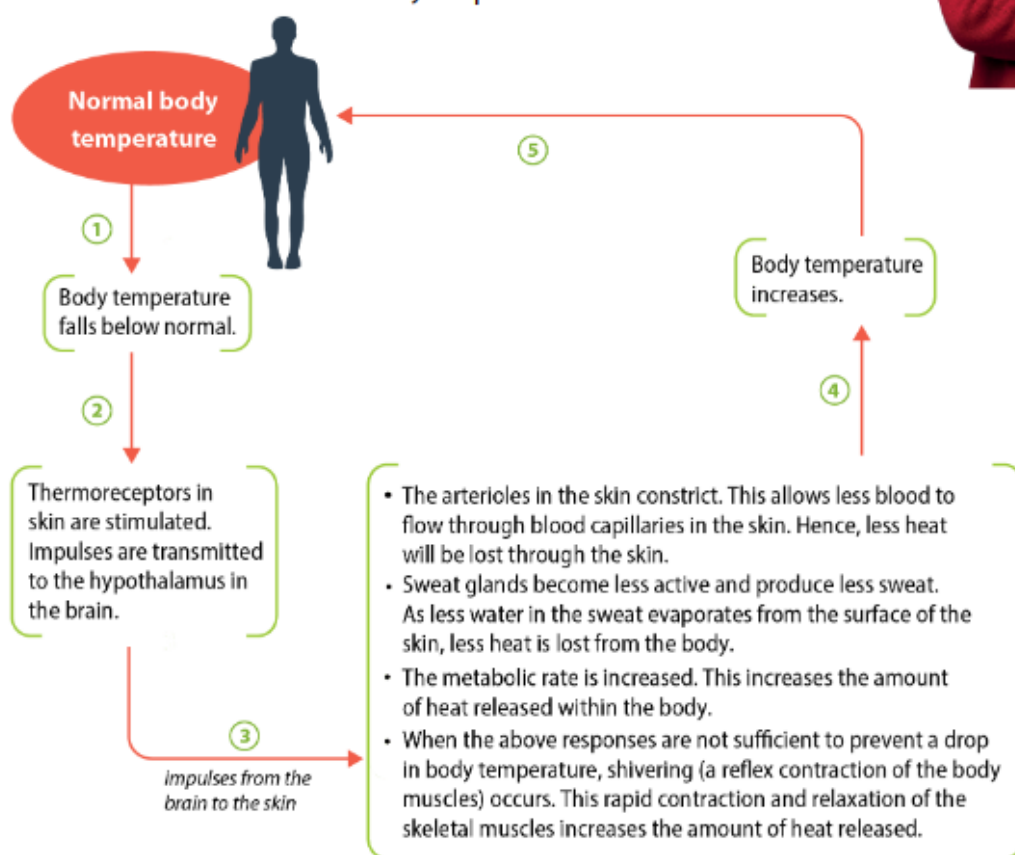


Figure 9.16 Homeostatic control of body temperature through negative feedback loop when the temperature rises



What Happens When the Body Temperature Begins to Fall?

On a cold day, the rate of heat loss from the body increases, especially at the skin surface. A drop in temperature at the skin surface stimulates the thermoreceptors in the skin to rapidly send nerve impulses to the hypothalamus. A drop in the temperature of the blood is also detected by the hypothalamus. In both cases, the hypothalamus will promptly send nerve impulses to the relevant parts of the body to bring about certain changes within the body (Figure 9.17). These changes will cause an increase in the body temperature.



Link

Physics

Our body can gain or lose heat through thermal processes, such as conduction, convection and radiation. This involves transfer of energy to achieve internal equilibrium.

Figure 9.17 Homeostatic control of body temperature through negative feedback loop when the temperature falls

In conditions of prolonged exposure to extremely cold temperatures, frostbite may occur. Fingers may lose their sensation, ice crystals form around the cells, causing death and destruction of the cells in the skin. How does exposure to extremely cold temperatures cause frostbite?



Let's Investigate 9.1

Mammals, including humans, are warm-blooded organisms that maintain a constant body temperature.

Aim

To simulate body temperature regulation in mammals

Procedure

- 1 Prepare two cups as shown in Figure 9.18. The tissue paper around cup B is held in position by two rubber bands.

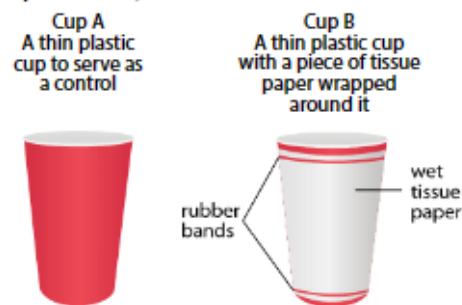


Figure 9.18

- 2 Thoroughly wet the tissue paper around cup B with some hot water (at 70 °C) using a dropper. Do not allow the tissue paper to become dry.
- 3 Three-quarter fill each cup with hot water (at 70 °C). Each cup should contain the same depth of water.
- 4 Measure the temperature of the water in each cup using a thermometer. Record the temperature using Table 9.2.

Table 9.2

Time (minutes)	Cup A	Cup B
0		
4		
8		
12		
16		
20		

- 5 Repeat the readings after 4, 8, 12, 16 and 20 minutes. Stir the water with a glass rod before each reading is taken.

Questions

- 1 Which cup cooled more rapidly? Give a reason for your answer.
- 2 If the cups were left for a few hours, what would be the final temperature of the water in each cup?
- 3 Mammals, including humans, are warm-blooded organisms with a constant body temperature. They regulate their body temperature through homeostasis. Some mammals have sweat glands to cool down by sweating. Suggest how this experiment helps you to understand the ways by which mammals maintain a constant body temperature.



Link

Practical Workbook
Experiment 9A

The stages involved in the homeostatic control of body temperature is summarised in Figure 9.19.

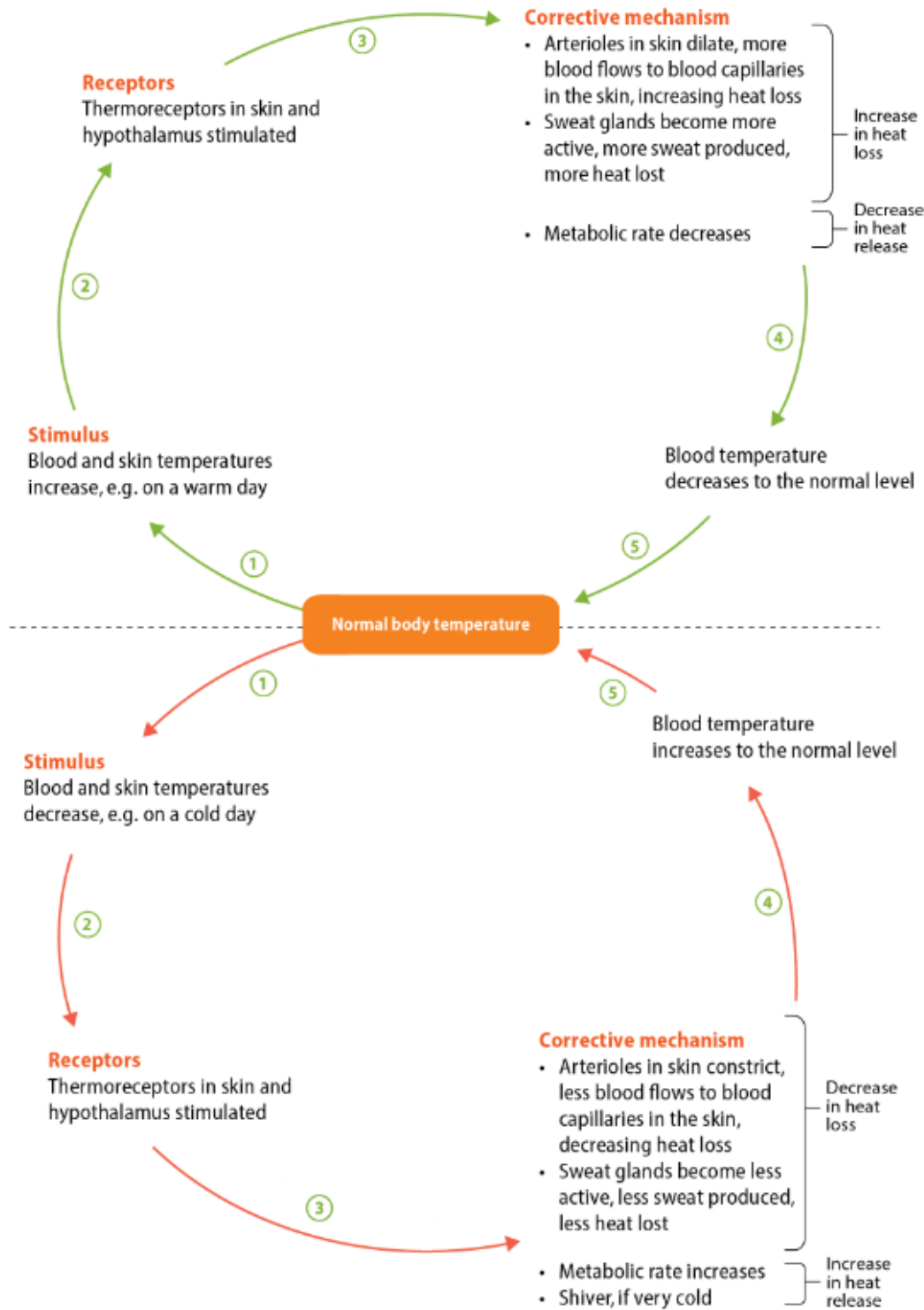


Figure 9.19 Summary of the homeostatic control of body temperature



Disciplinary Idea

Homeostasis, Coordination and Response

Living organisms require a constant internal environment to maintain optimum conditions for cells to live and function. To be independent from changes in the external environment, living organisms can detect and respond to changes both from the surrounding environment and within themselves through restoring the system to its original state.

Let's Practise 9.3

- 1 Figure 9.20 shows the vertical section of the human skin.
 - (a) Identify the structures labelled A to C.
 - (b) For each structure in (a), describe its function.

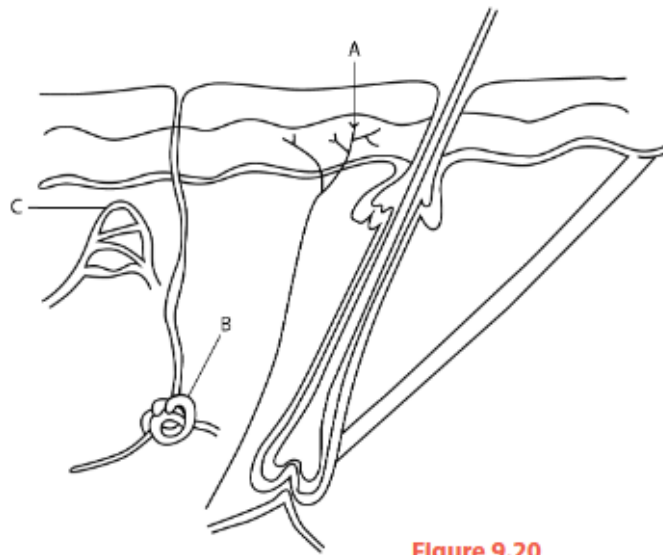


Figure 9.20

- 2 Explain how the muscles in the skin arterioles help to control body temperature.
- 3 State **two** ways by which the body:
 - (a) gains heat
 - (b) loses heat



Link

Theory Workbook
Worksheets 9C–9D
Let's Assess
Let's Reflect



Problem-based Learning Activity

F1 drivers such as those who race in the Singapore Grand Prix can lose up to 3 kg of weight after each race. This is mainly due to the loss of water in the body, despite sitting in a car throughout the race. What will happen to the driver if he does not replenish the water that is lost during the race? Can you propose a strategy to help prevent dehydration of the body in such instances?

Use the following guidelines to discuss:

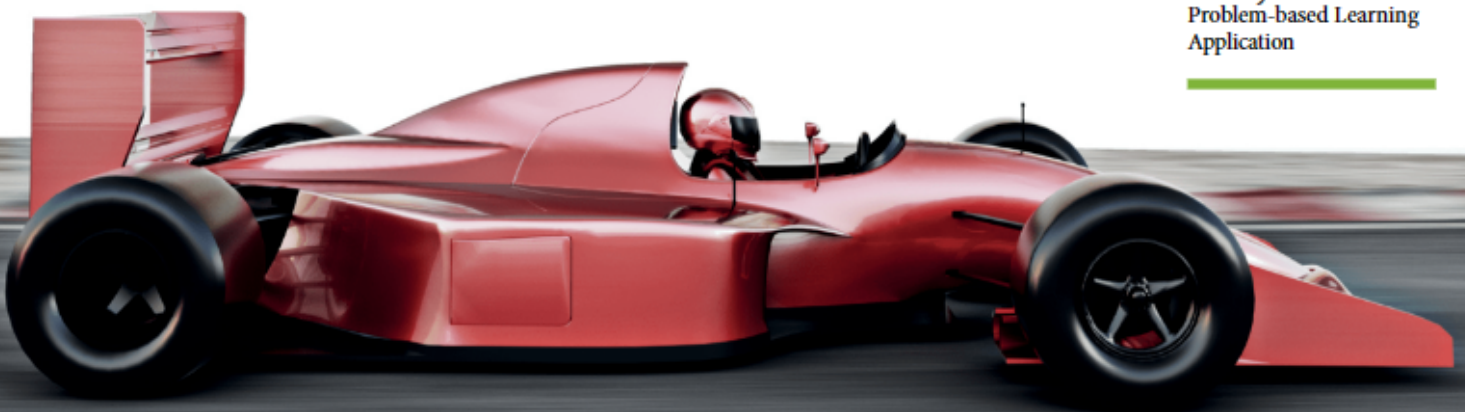
- 1 The temperature in the cockpit of an F1 race car can often exceed 40 °C during a race. What contributes to the increase in temperature?
- 2 What might contribute to the water loss that the driver experiences?
- 3 Recall the processes in homeostasis that involve the loss of water. Ask yourself the following questions:
 - What does losing water do for the body?
 - Which organs in the body expel water for this purpose?
- 4 Recall the different parts of the organ responsible for regulating the body temperature.
- 5 Study the processes involved in the regulation of body temperature and water potential (refer to Figures 9.3 and 9.19). At the same time, relate to the structure of the human skin and take note of how different parts of the body need to act in sequence to restore balance.
- 6 Propose a method to prevent the dehydration of the race car driver's body during a race. For example, your method could be as follows:
 - a sequence of activities that the driver should take before, during or after the race

Remember to support the method which you have proposed with explanations that are based on what you have learnt from your discussion above. You should also consider the impact on the race performance should your method be adopted.

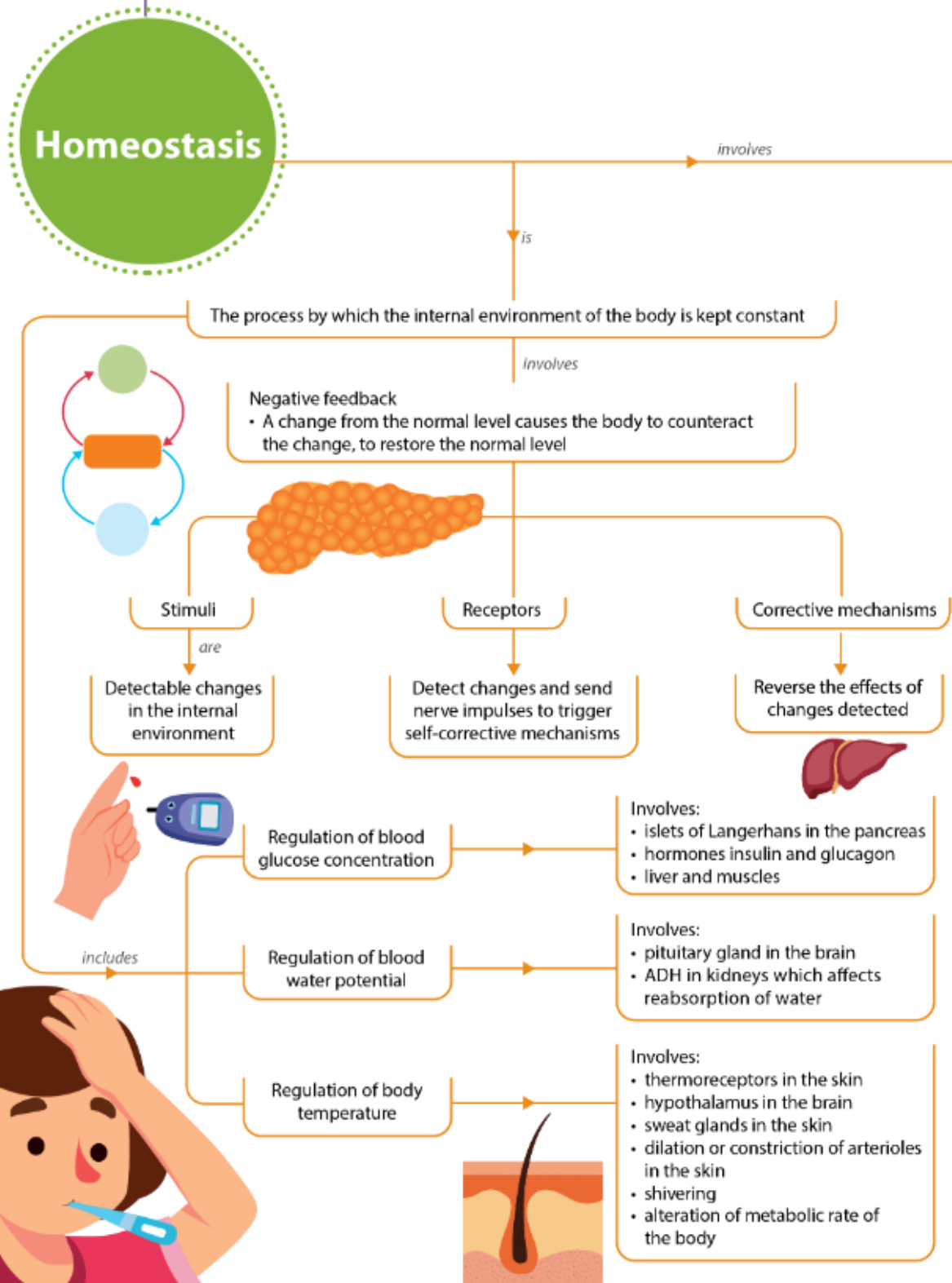


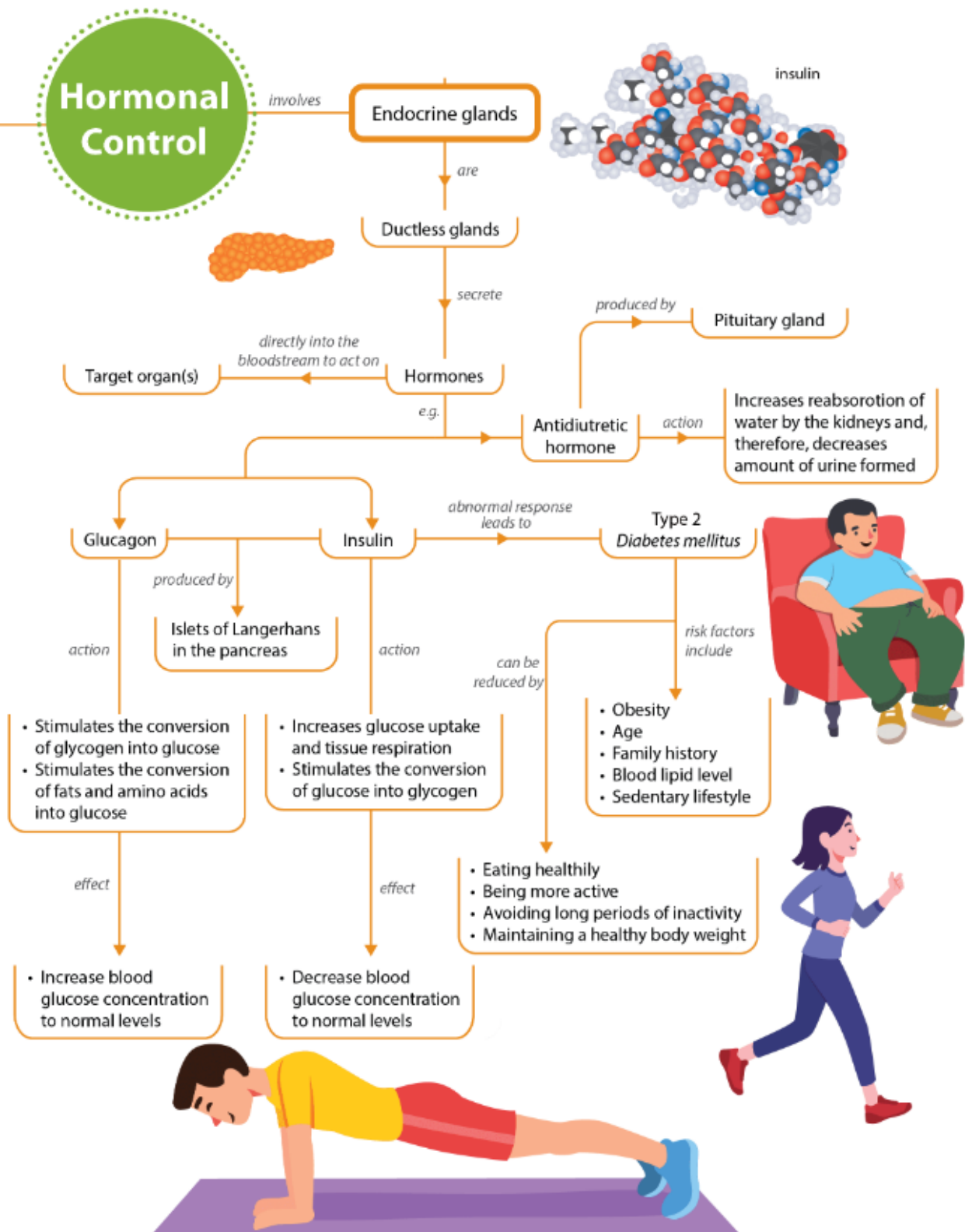
Link

Theory Workbook
Problem-based Learning
Application



Let's Map It





Let's Review

Section A: Multiple-choice Questions

1 Which of the following shows where insulin is produced and where it acts?

	Site of Production	Site of Action
☐ A	liver	pancreas
☐ B	pancreas	liver
☐ C	islets of Langerhans	pancreas
☐ D	liver	kidneys

2 Which of the following substances enters the blood from the pancreas?

- ☐ A glycogen ☐ B glucagon
☐ C lipase ☐ D pancreatic juice

Refer to the graph below to answer questions 3 and 4. Figure 9.21 shows the changes in a person's body temperature over a period of time.

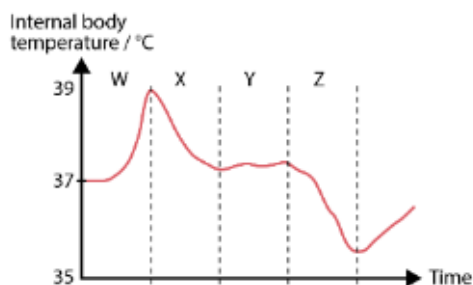


Figure 9.21

3 At which period would the skin arterioles first become dilated?

- ☐ A W ☐ B X ☐ C Y ☐ D Z

4 At which period would the skin arterioles first become constricted?

- ☐ A W ☐ B X ☐ C Y ☐ D Z

Section B: Structured Questions

1 Figure 9.22 shows how the concentration of blood sugar and the concentration of a certain hormone in a person's blood changed over a period of five hours.

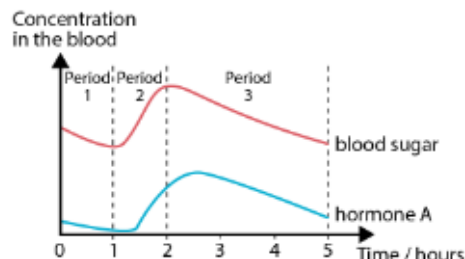


Figure 9.22

- Suggest a reason for the fall in the concentration of blood glucose during period 1.
- What happened at the end of period 1 to cause a rise in the concentration of blood glucose?
- What can you deduce about hormone A's relationship with blood sugar? Explain your deduction.
- Children suffering from a lack of hormone A can be taught to inject the hormone into themselves. What precaution must they take when doing this?

2 Complete Table 9.3.

Table 9.3

Hormone	Endocrine Gland	One Effect of Hormone
Insulin		
ADH		

- Explain the role played by the following in the regulation of body temperature:
 - blood vessels in the skin
 - the brain
 - the muscles of the body

Section C: Free-response Questions

- What is type 2 diabetes?
 - How does a person reduce his risk of getting type 2 diabetes?
- Consuming alcohol causes the muscles in the walls of the arteries to relax. Based on this information, suggest why people who work in temperate regions where temperature is below 5 °C might be advised not to drink alcohol before work.

CHAPTER



10

The Nervous System and the Eye



What You Will Learn



- What makes up the human nervous system?
- What is the structure of the human eye?
- How do we see?

Place your finger 10 cm to 15 cm from your nose and look hard at it. Then focus on the objects behind the finger. How many fingers do you see now? Why are your eyes playing these tricks on you?



10.1 What Makes Up the Human Nervous System?

Learning Outcomes

- State that the nervous system — brain, spinal cord and nerves, serves to co-ordinate and regulate bodily functions.
- Outline how receptors, sensory neurones, relay neurones (located in the spinal cord or brain), motor neurones and effectors work together to produce a co-ordinated response in a reflex action as a result of a specific stimulus.

Are you able to prevent yourself from laughing when you are tickled? You would probably burst into laughter every time someone tickles you. So do most people. The tickle response is a natural reflex action. How does the body bring about this response?

What Is Sensitivity?

A living organism is able to react to changes in its surroundings. Any change in the environment that causes an organism to react is called a **stimulus** (plural: **stimuli**). An organism's reaction to a stimulus is called a **response**.



Link

The eye is an example of a highly specialised sense organ. Learn more about it in Sections 10.2 and 10.3.

How Does an Organism Usually Respond to a Stimulus?

Here are some examples:

- Plants need light for photosynthesis, so they grow towards light. This response occurs over time.
- *Euglena*, a single-celled organism, makes food by photosynthesis. *Euglena* swims towards light.
- Some organisms, such as cockroaches, move away from light. They hide in dark areas during the day.

The ability to respond to a stimulus is termed **sensitivity** or irritability.



What Is the Role of the Nervous System in Humans?

The nervous system in humans regulates bodily functions and activities and how we react to the surroundings (responses to stimuli). The nervous system consists of a well-developed brain, spinal cord, spinal nerves and highly specialised **sense organs**. These sense organs detect changes in the environment.

In humans, many activities such as the heartbeat, peristalsis and breathing movements are automatic and are not controlled consciously. They are called **involuntary actions**. Activities that are controlled consciously are called **voluntary actions**. All these various activities performed by the body are controlled by the nervous system.

Components of the Human Nervous System

The nervous system (Figure 10.1) is made up of:

- the **central nervous system (CNS)** consisting of the brain and the spinal cord
- the **peripheral nervous system (PNS)** consisting of the cranial nerves (from the brain), the spinal nerves (from the spinal cord) and the sense organs

The sense organs receive stimuli through **receptors** found in them. They inform the central nervous system of any change in the surroundings, by producing electrical signals or messages called **nerve impulses**. These nerve impulses are carried or **transmitted** to the central nervous system by **nerves** (cranial nerves and spinal nerves). A nerve impulse is transmitted within a fraction of a second.

For example:

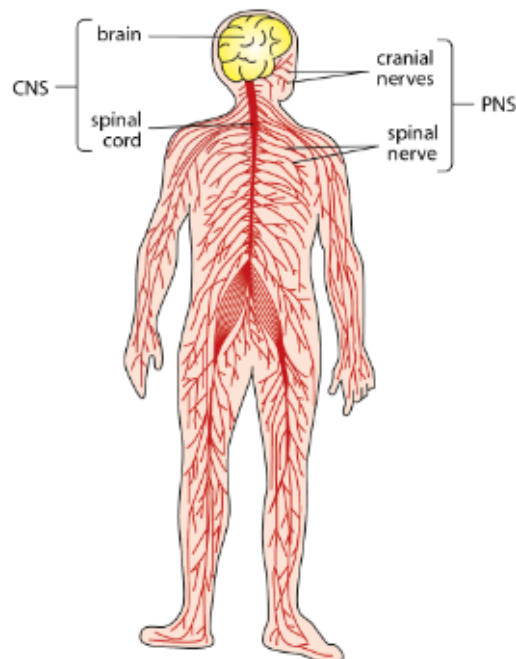
- 1 When a person touches your hand, you feel it almost immediately.
- 2 In response to this stimulus, the central nervous system will send nerve impulses to the muscles.
- 3 The muscles will then effect an action. For example, the muscles in the arm may contract, and the hand is jerked away. Therefore, muscles are known as **effectors**.

Nerves transmit nerve impulses from the receptors to the central nervous system, and from there to the effectors (Figure 10.2).



Figure 10.2 How nerve impulses are transmitted by nerves

The nervous system is a device for gathering, transmitting and interpreting information — just like a very complex and powerful computer!



Word Alert

Peripheral: on the outer side or edge

Figure 10.1 The general arrangement of the brain, spinal cord and nerves in humans



Helpful Note

Receptors detect changes in the environment (receive stimuli), while the effectors respond to the processed stimuli.

Neurones

The nervous system is made up of nervous tissue. Nervous tissue consists of nerve cells called **neurones**. Figure 10.3 shows the connection between three types of neurones.

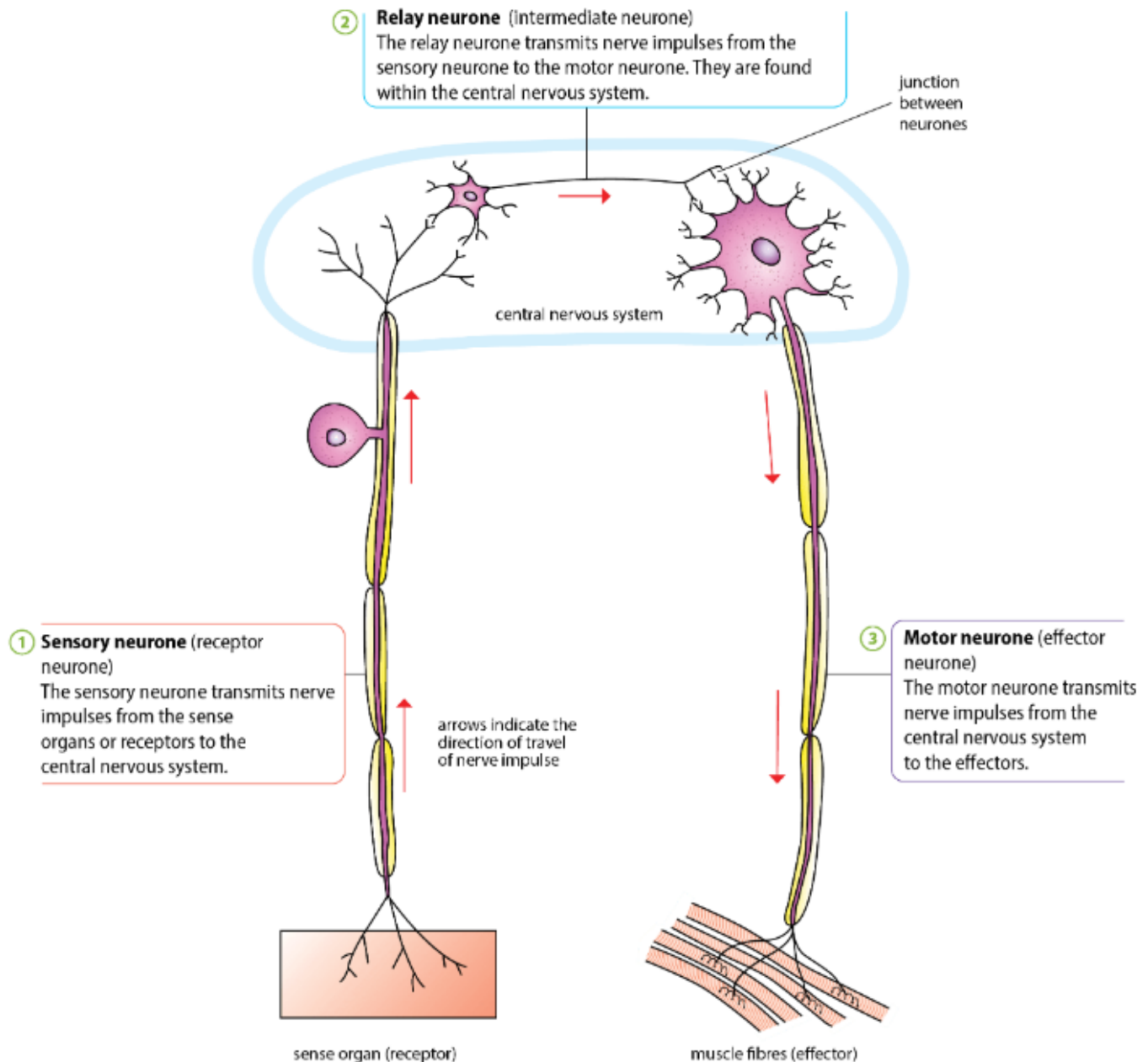


Figure 10.3 Relation between a sensory neurone, a relay neurone and a motor neurone

Although the size and shape of neurones differ in different parts of the nervous system, they are basically similar. Each neurone consists of a cell body containing a nucleus and cytoplasm, and a number of nerve fibres. A **nerve fibre** is a strand of cytoplasm extending from the cell body.



What Is the Structure of a Motor Neurone?

Figure 10.4 shows the structure of a motor neurone.

Cell body

The **cell body** contains a nucleus, cytoplasm, cell membrane and organelles. The cell body of a motor neurone is irregular in shape.

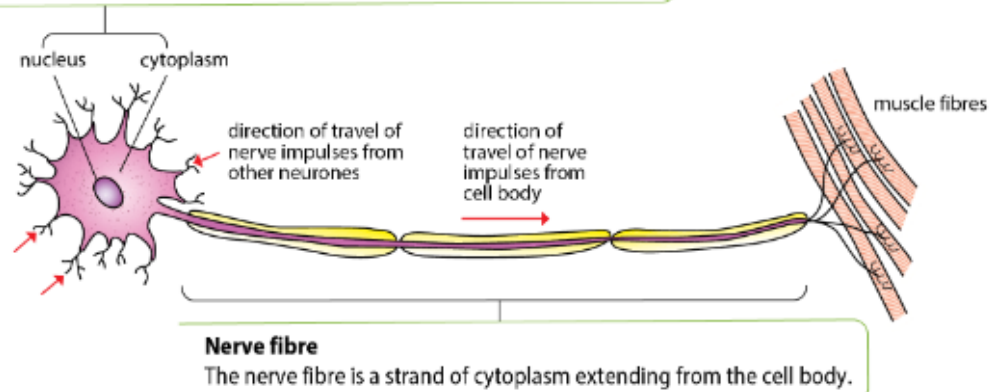


Figure 10.4 Structure of a motor neurone

What Is the Structure of a Sensory Neurone?

The sensory neurone has a circular cell body. It has one long nerve fibre extending towards the receptor and a short nerve fibre extending towards the relay neurone in the central nervous system (Figure 10.5).

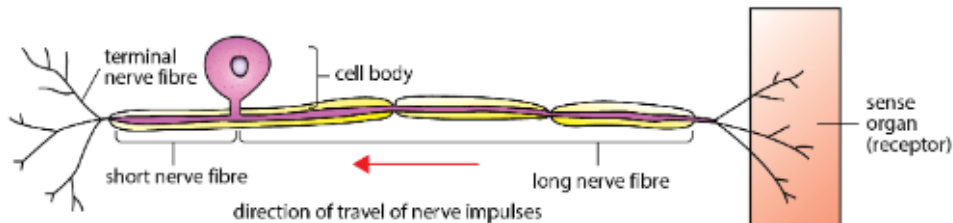


Figure 10.5 Structure of a sensory neurone

What Is a Synapse?

Look at Figure 10.6. You may notice that there is a tiny space at the junction between two neurones. The junction between two neurones is called a **synapse**. Nerve impulses cannot directly cross from one neurone to the next due to the tiny space between them. Nerve impulses are transmitted across a synapse by chemicals released by the neurones.

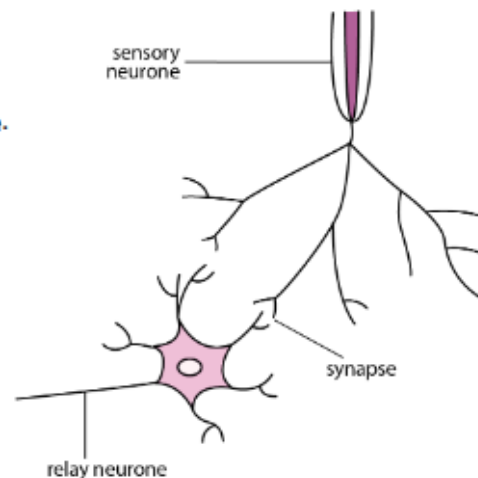


Figure 10.6 Synapse between a sensory neurone and a relay neurone

How Do the Brain, Spinal Cord and Spinal Nerves Work Together?

You have learnt that nerve impulses are transmitted by neurones to and from the central nervous system. The spinal cord and the brain are parts of the central nervous system.

The brain is contained within the skull which protects it. From the brain, the spinal cord runs down the back of the body. The spinal cord passes through the vertebral column (backbone) which protects it.

Spinal nerves connect the spinal cord to various parts of the body. Like all nerves, they are composed of bundles of nerve fibres (Figure 10.7).

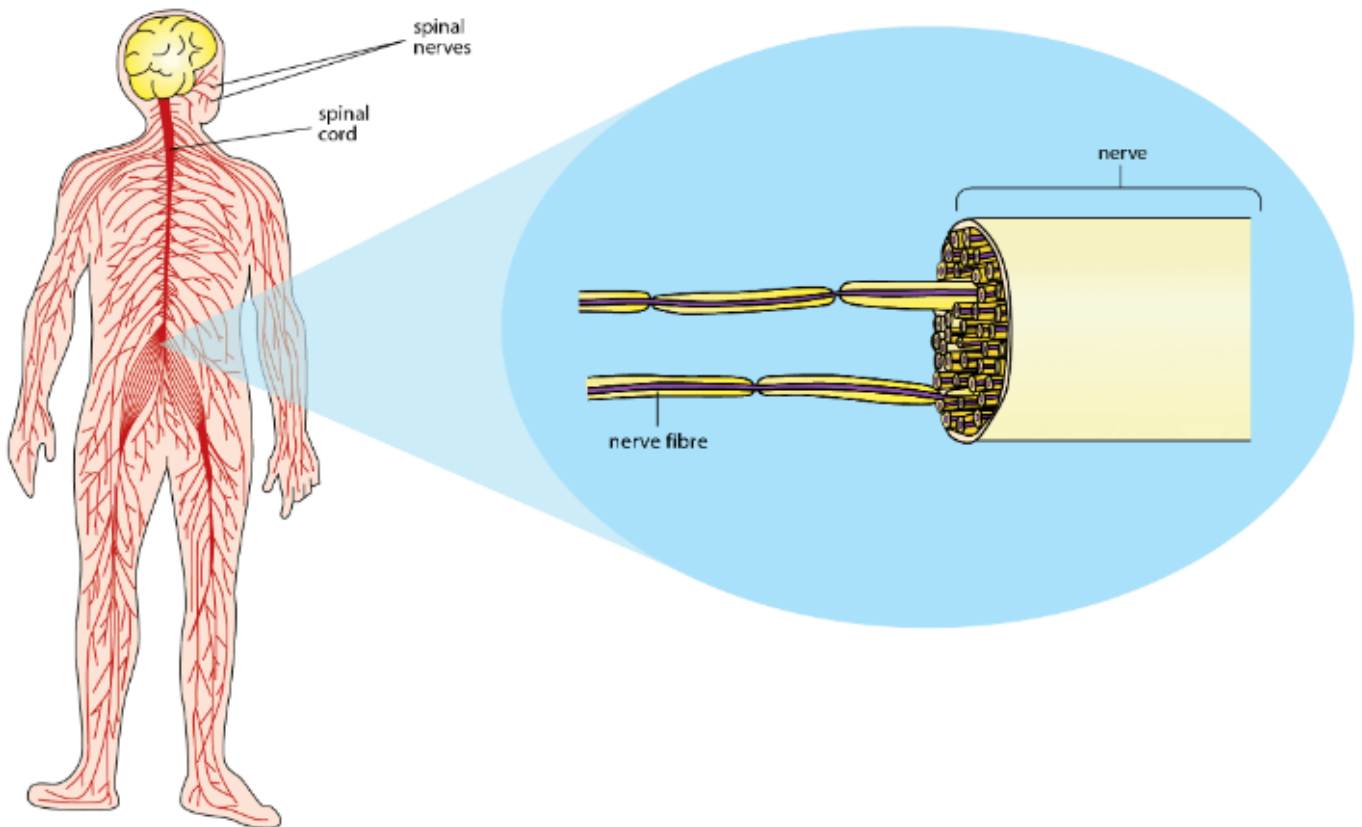


Figure 10.7 Spinal cord and spinal nerves in the human body

Spinal nerves emerge at intervals along the length of the spinal cord. As the spinal nerve leaves the spinal cord, it progressively subdivides into branches supplying nerve fibres to various parts of the body.



Figure 10.8 shows a transverse section of the spinal cord through the region containing the spinal nerves.

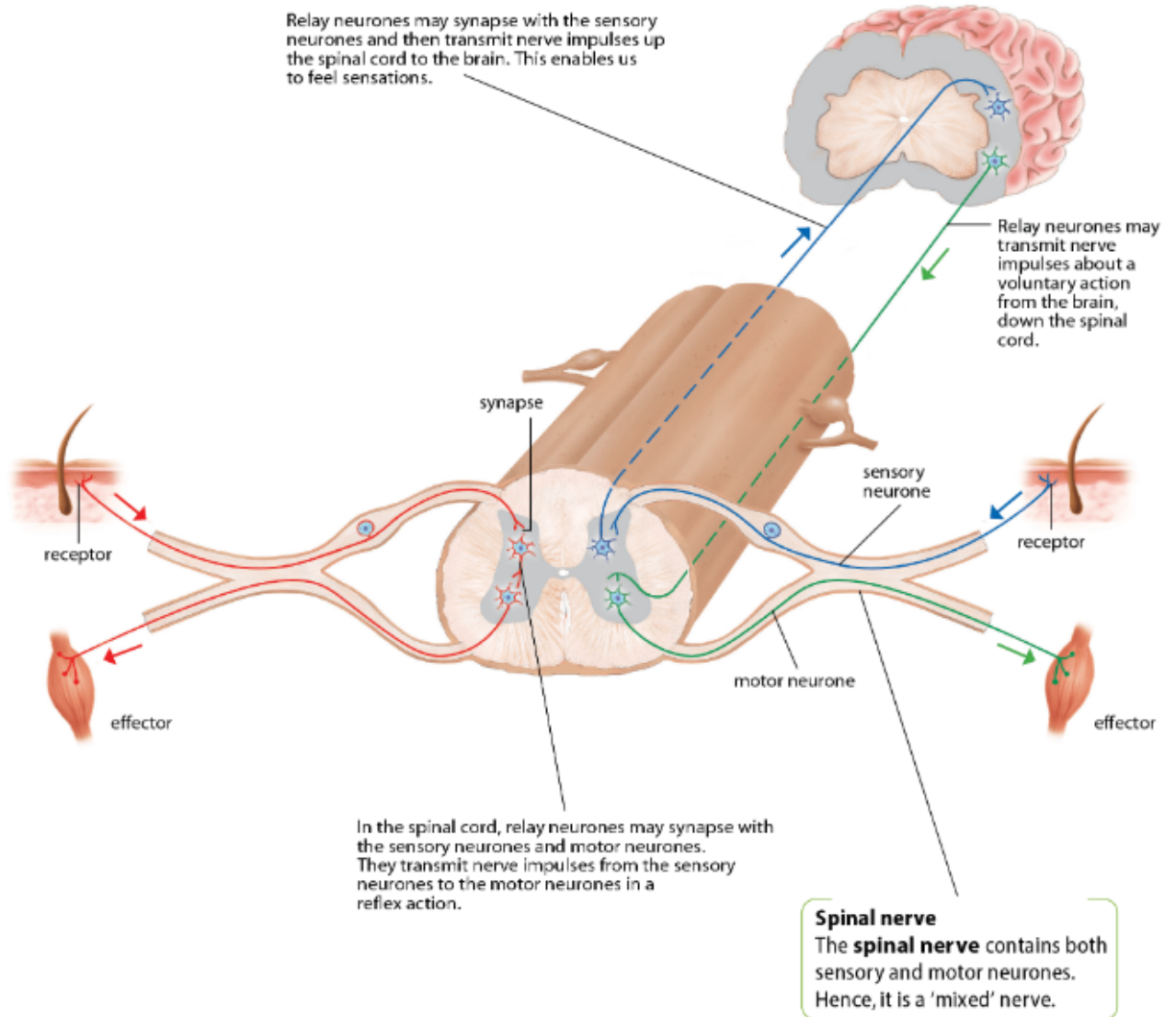


Figure 10.8 Portion of spinal cord showing the pathway of nerve impulses

As you may notice in Figure 10.8, synapses occur in the central inner part of the spinal cord, which transmits nerve impulses to and from the brain.



Tech Connect

Damage to the spinal cord could paralyse a person from neck down. Such a person may only be able to turn his head but not move any other part of his body for the rest of his life. With advances in computer and biomedical engineering technologies, there is hope for rehabilitation. Biomedical engineers and neuroscientists have been experimenting with brain implant technology. They implant sensors into the brain of a paralysed person. They connect the sensors to a computer. The computer is in turn connected to an artificial body part to stimulate specific muscles in the arm and hand. This creates an artificial neural loop that connects the brain to the muscles, bypassing the damaged spinal cord. The results of these early studies have been promising, with the victim being able to perform simple actions like holding simple objects and even self-feeding. While there is still a lot to do, this emerging field could change the lives of millions of people who are paralysed.



Figure 10.9 Using brain implant technology to help a paralysed person walk again



Figure 10.10 The hand feels cold when thermoreceptors in the skin are stimulated.

How Does the Nervous System Process Information?

Sensation

When you hold a piece of ice, you can feel its coldness (Figure 10.10). This is because the temperature receptors in your skin are stimulated. Nerve impulses are produced and transmitted to the brain. The brain interprets the nerve impulses, and you have a **sensation** of coldness.

The pathway of nerve impulses is shown in blue in Figure 10.8. It can be summarised as follows:



Voluntary Action

Recall that a **voluntary action** is under conscious control. This means it is a **deliberate** action.

For example, you decide to raise your hand to answer a question in class (Figure 10.11). Nerve impulses are produced in the brain. The nerve impulses are transmitted by a relay neurone from the brain, down the spinal cord. In the spinal cord, nerve impulses are transmitted to the motor neurone, which transmits the nerve impulses to the effector muscles in your arm. The muscle contracts, and your hand is raised.

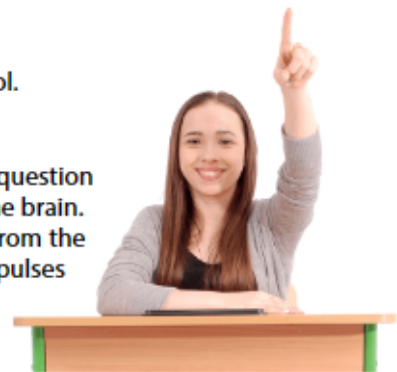


Figure 10.11 Raising the hand to ask a question is a voluntary action.

The pathway of nerve impulses is shown in green in Figure 10.8. It can be summarised as follows:



What Is a Reflex Action?

If you touch something hot, your hand immediately withdraws without you having to think about it. This type of response is called a reflex action.

- ▶ A **reflex action** is an immediate response to a specific stimulus without conscious control.



Word Alert

Deliberate: intentional, on purpose

Reflex actions are rapid and automatic. They are the simplest form of response in humans and can occur without any conscious effort. In fact, it is normally not possible to prevent them consciously. Reflex actions are examples of involuntary actions.

The spinal cord and the brain are **reflex centres**. Reflex actions may be classified as follows:

- **Cranial reflexes**
These are controlled by the brain (but not the conscious will) and usually occur in the head region. Examples include pupil reflex, blinking and salivation.
- **Spinal reflexes**
These are controlled by the spinal cord. Examples include the sudden withdrawal of the hand on touching a hot object (Figure 10.12) and knee-jerk reflex.



Figure 10.12 Withdrawal of the hand due to a hot object is a spinal reflex.

What Happens When Your Hand Touches a Hot Object?

The sudden withdrawal of the hand on touching a hot object is an example of a simple spinal reflex action. The events in such a reflex action are summarised in Figure 10.13.

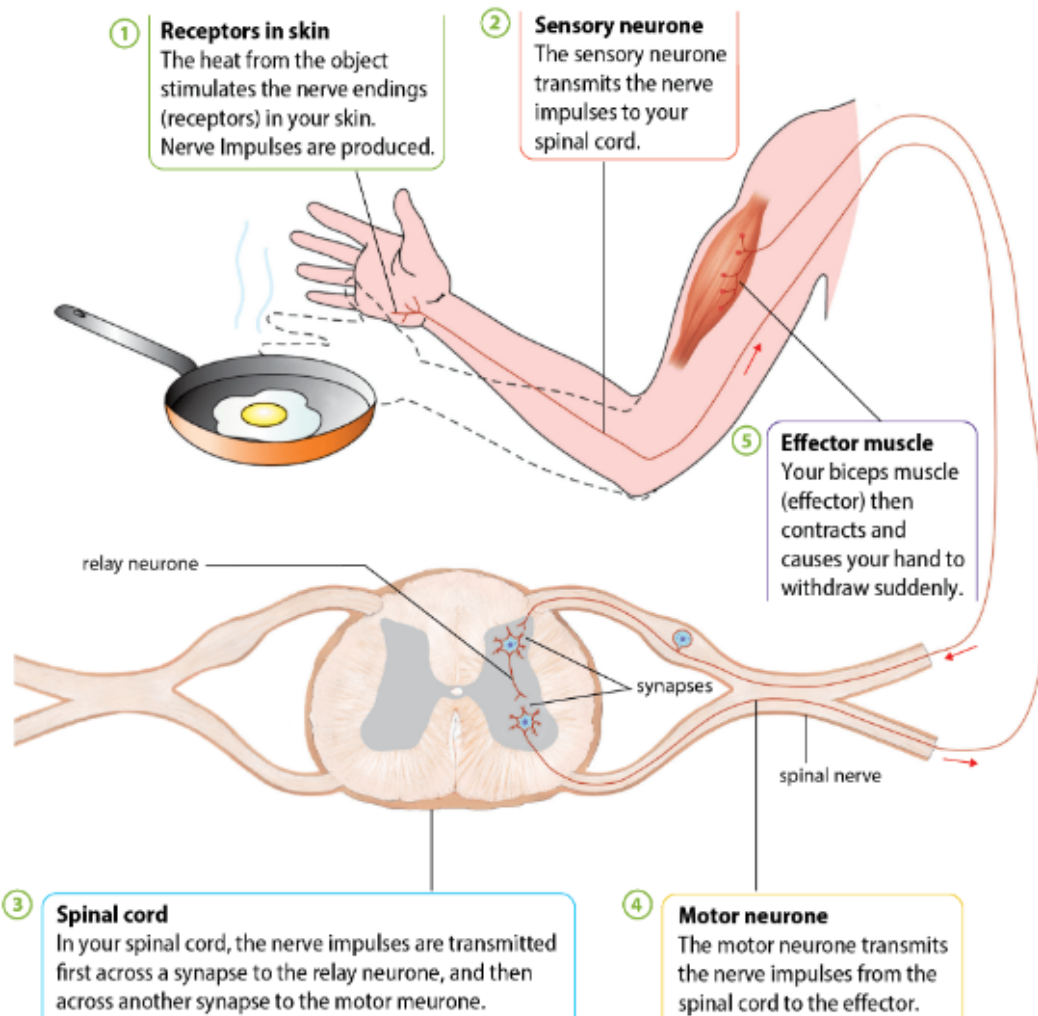


Figure 10.13 Sequence of events in a reflex action

What will happen to a person holding a hot object if his sensory or motor neurone is cut? Figure 10.14 shows two people giving their explanations. Comment on their explanations.



Figure 10.14
Two people are discussing reflex actions. Comment on the statements they make.

Let's Investigate 10.1

- 1 Sit down and cross one leg over the other in such a way that the shin of your upper leg can swing freely. (The shin is the front part of your leg below the knee.)
- 2 Ask your friend to give you a sharp tap just below the kneecap with the edge of his or her hand. What happens?
- 3 Now try it again, this time with your hand resting on the thigh of your upper leg. What feeling do you get in your upper thigh muscle? Is the momentary kicking of your leg an automatic reaction? Can you control it?

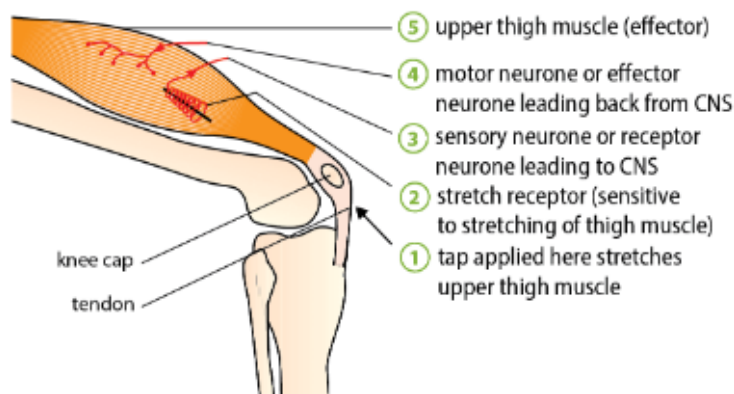


Figure 10.15 Knee-jerk reflex

The reaction in the activity you just did is an immediate response to a specific stimulus. The stimulus in the knee-jerk reflex is the sudden tapping below the kneecap.



What Is a Reflex Arc?

In a reflex action, there is a particular pathway by which the nerve impulses can travel from the receptor to the effector. This nervous pathway is known as the *reflex arc* (Figure 10.16).

- ▶ A **reflex arc** is the shortest pathway by which nerve impulses travel from the receptor to the effector in a reflex action.

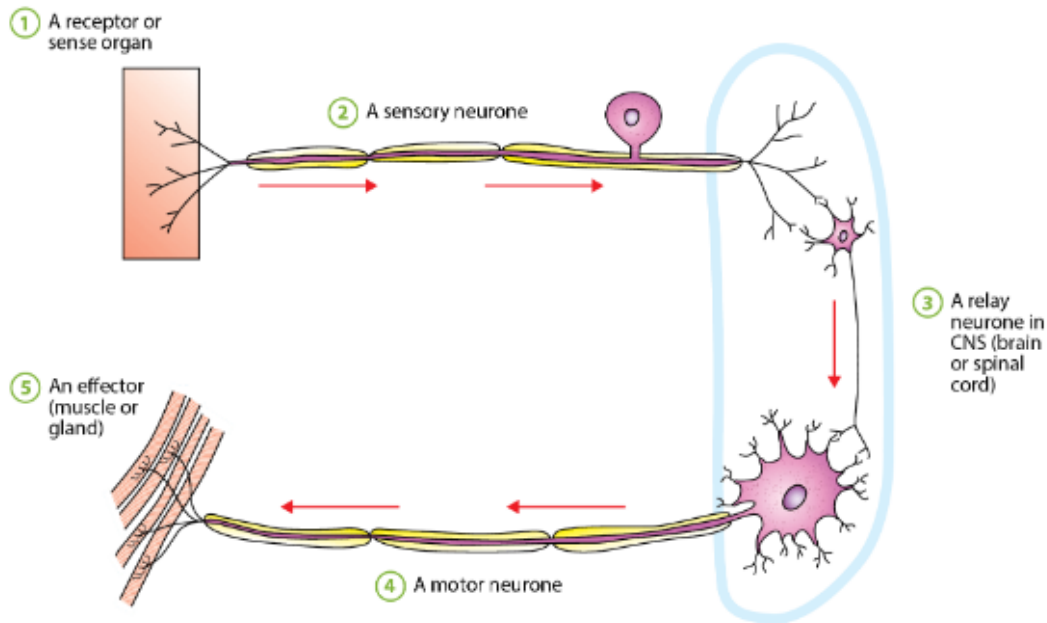
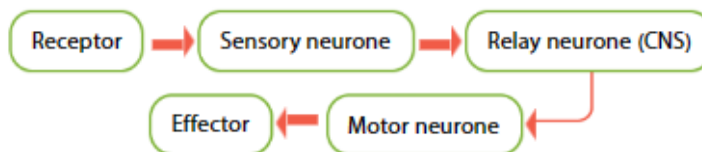


Figure 10.16 Simple reflex arc

The nervous pathway in a reflex arc can be written as follows:



Cool Career

Biomedical Engineer

Biomedical engineers study human reflex and voluntary actions. They design and maintain equipment and devices such as body parts replacements, artificial limbs or prosthetics, and machines to diagnose diseases. These experts combine knowledge of biology, physics and computing to bring about new technologies in products. Such products (Figure 10.17) could change the lives of many people who may be paralysed or struggle with problems of the nervous system.



Figure 10.17 Artificial hand

How Are Endocrine (Hormonal) Control and Nervous Control Different?

The endocrine (hormonal) system, like the nervous system, serves as a means of co-ordination within the body. In both cases, a stimulus causes the transmission of a message to a **target organ (effector)** which carries out the response. For example, a decrease in the water potential of the blood (stimulus) causes more antidiuretic hormone (ADH) to be produced by the pituitary gland and transported to the kidneys. ADH increases the permeability of the walls of the collecting ducts to water so that the kidneys respond by reabsorbing more water (effect).

However, the nervous control differs from the endocrine control in several ways. For example, nervous control may affect only a particular part of the body, i.e. it is **localised**. Since hormones are usually transported around the body by the blood, several target organs may be affected by the same hormone. An example of this is the effects of the hormone adrenaline on the heart, arteries, iris and metabolic rate.

The differences between endocrine control and nervous control are shown in Table 10.1.

Table 10.1 The differences between the endocrine and nervous controls

Endocrine Control	Nervous Control
Involves hormones (chemical substances) as signals	Involves nerve impulses as signals
Hormones are transported by the blood	Nerve impulses are transmitted by neurones
Usually slow responses	Usually quick responses
Responses may be short-lived (e.g. adrenaline) or long-lived (e.g. growth hormone)	Responses are short-lived
Always involuntary	May be voluntary or involuntary
May affect more than one target organ	Usually localised

Let's Practise 10.1

- 1 Using an example, distinguish between a *stimulus* and a *response*.
- 2 What are the components of the nervous system?
- 3 Name **three** types of neurones.
- 4 Name the junction where two neurones meet.
- 5 What is a reflex action?
- 6 Functions in the human body are controlled by two systems. Name and briefly compare the two controls.



Link

Recall what you have learnt in Chapter 9 on hormones and the endocrine system.



Disciplinary Idea

System

Components within the endocrine and nervous systems work together to allow co-ordinated responses to internal and external stimuli.



Link

Theory Workbook
Worksheet 10A

10.2 What Is the Structure of the Human Eye?

Learning Outcomes

- Describe the structure of the eye as seen in front view and in horizontal section.
- Describe the pupil reflex in response to bright and dim light.

There are smells and sounds that many animals can detect but not us. However, the world that we see is more colourful compared to the world seen by those animals. We rely more on our sense of sight to perceive the world around us.

The **eye** is the sense organ responsible for sight. In humans, each eyeball lies in a hollow in the skull called the **orbit**. Each eyeball is attached to the skull by **rectus muscles** (Figure 10.18). The rectus muscles control eye movement.

What Forms the External Structure of the Eye?

The front part of the eyeball is covered by **eyelids**. Only a part of the eyeball can be seen. Figure 10.19 shows the structures that are found at the front part of the eye. Table 10.2 provides information about the parts and their functions.

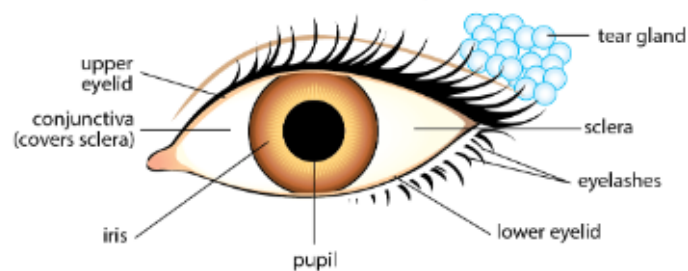


Figure 10.19 Parts at the front of the eye

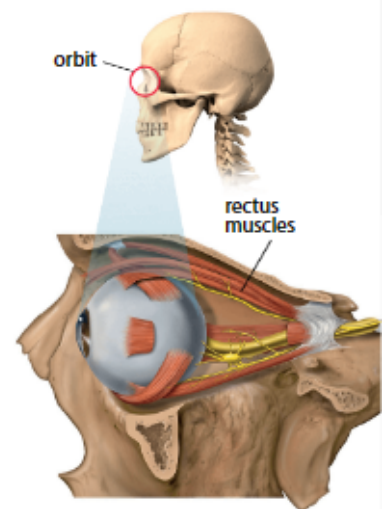


Figure 10.18 Rectus muscles of the eyeball

Table 10.2 Parts at the front of the eye and their functions

Part	Description
Sclera (or sclerotic coat)	The sclera is the 'white of the eye'. It is a tough, white outer covering of the eyeball. It is continuous with the cornea, which is a dome-shaped transparent layer at the front of the eye. It protects the eyeball from mechanical damage.
Conjunctiva	The conjunctiva is a thin transparent membrane covering the sclera in front. It is a mucous membrane. It secretes mucus, thus helping to keep the front of the eyeball moist.
Eyelashes	The eyelashes help to shield the eye from dust particles.
Tear gland	The tear gland lies at the corner of the upper eyelid. It secretes tears that: • wash away dust particles • keep the cornea moist for atmospheric oxygen to dissolve so that the dissolved oxygen can diffuse into the cornea • lubricate the conjunctiva, helping to reduce friction when the eyelids move
Eyelids	The eyelids protect the cornea from mechanical damage. They can be partly closed. This is known as squinting. Squinting prevents too much light from entering the eyelid and damaging the retina. Blinking spreads tears over the cornea and conjunctiva, and wipes dust particles off the cornea.
Iris	The iris is a circular sheet of muscles. It controls the size of the pupil and therefore the amount of light entering the eye. It contains a pigment that gives the eye its colour.
Pupil	The pupil is a hole in the centre of the iris. It allows light to enter the eye.



Word Alert

Lubricate: make smooth and slippery



What Forms the Internal Structure of the Eye?

Figure 10.20 shows the internal structure of the eye.

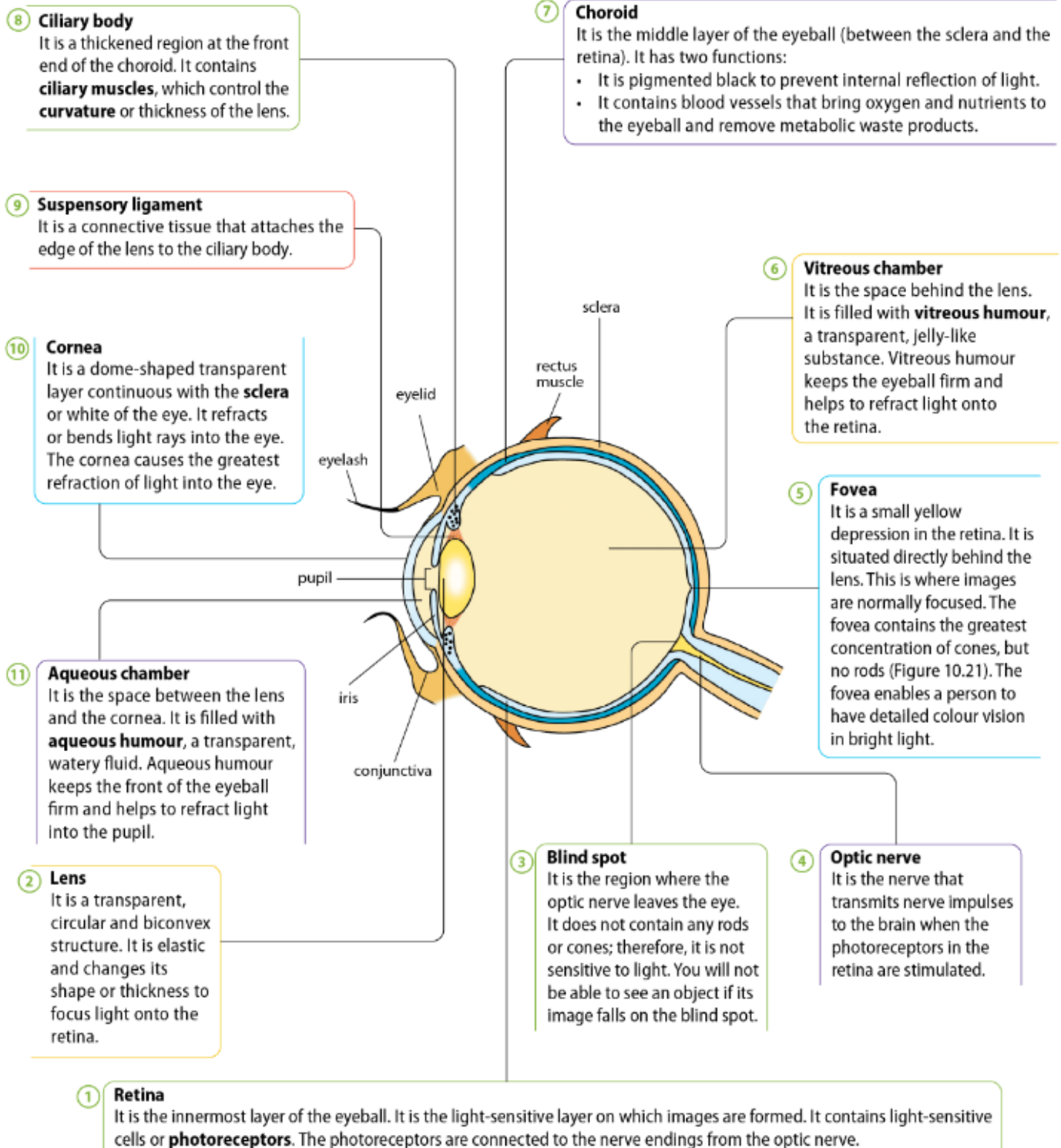


Figure 10.20 Vertical section of the eye



Helpful Note

Receptors that detect light changes are called **photoreceptors**. Photoreceptors in the retina consist of rods and cones. The photoreceptors are connected to the nerve endings from the optic nerve (Figure 10.21).

Cones enable us to see colours in bright light. They do not work well in dim light. The fovea contains only cones. It is where cones are the most densely packed in the retina. The fovea enables a person to have detailed colour vision in bright light. Rods are found throughout the retina except in the fovea. Rods are more sensitive to light than cones. They enable us to see in dim light, but only in black and white.

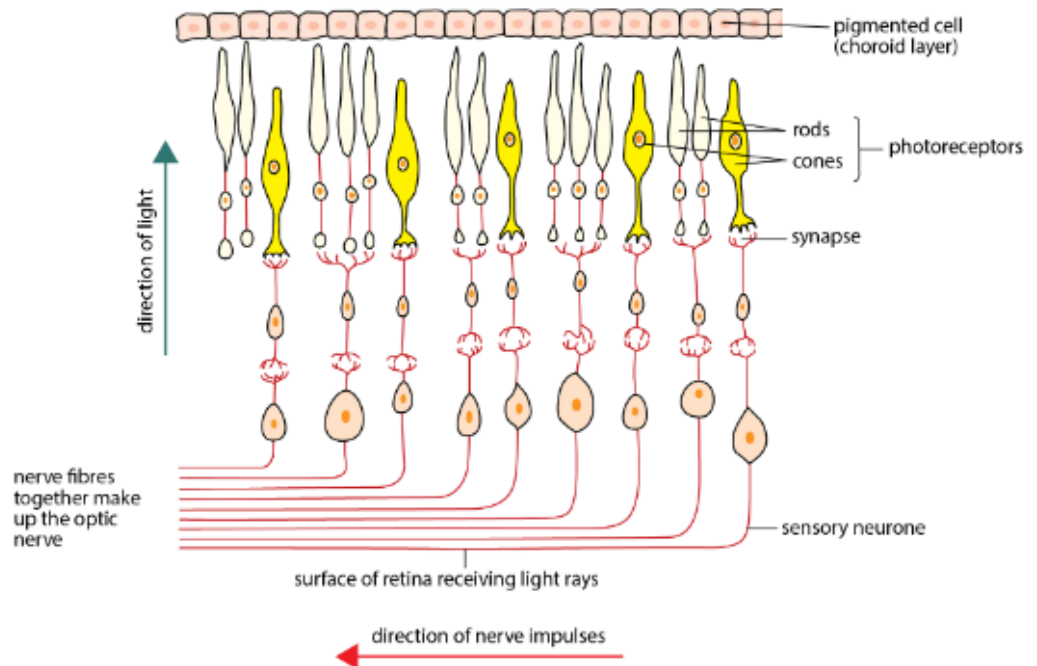


Figure 10.21 A section through the retina



Figure 10.22 Problems with pigments in the cones cause colour blindness. The image as seen by a person with normal vision is shown on the left. The same image as seen by a person who has trouble distinguishing between red and green is shown on the right.

What Is the Pupil Reflex?

In order for a person to see clearly, only the right amount of light should enter the eye. For example, more light must enter the eye in dim light. The size of the pupil determines how much light enters the eye.

The **pupil reflex** is a reflex action. The pupil changes in size in response to changes in light intensity (Figure 10.23). This is controlled by the iris.

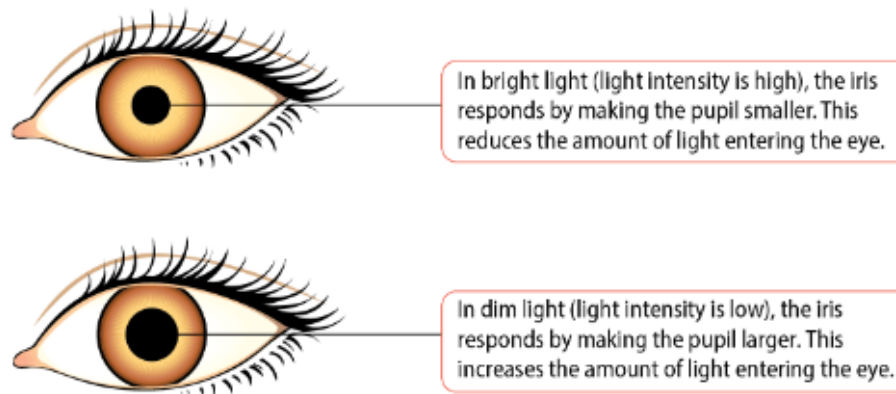


Figure 10.23 Pupil reflex

The pupil reflex is beneficial to the eyes in the following ways:

- 1 It is automatic, so no learning is required.
- 2 It prevents excessive light from entering the eye and damaging the retina.
- 3 It is an immediate response.
- 4 It allows enough light to enter the eye to allow us to see.

How Does the Iris Control the Amount of Light Entering the Eye?

The size of the pupil is controlled by two sets of involuntary muscles in the iris. These are the circular muscles and the radial muscles. The circular muscles are arranged in a circle round the pupil, while the radial muscles are arranged radially, like the spokes of a bicycle wheel. The circular and radial muscles are called **antagonistic muscles** because when one set contracts, the other set relaxes and vice versa (Figures 10.24 and 10.25).

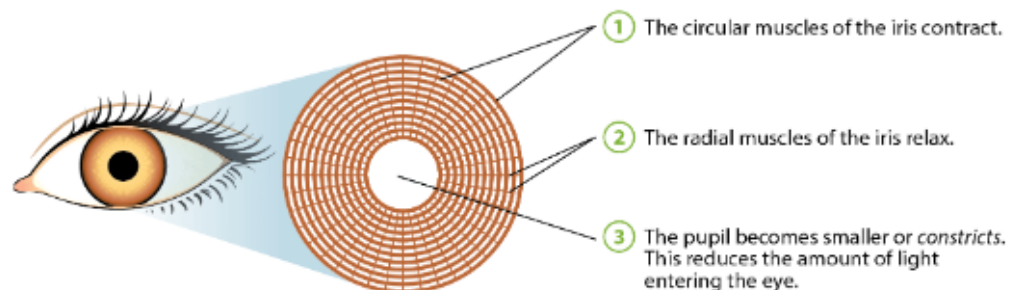


Figure 10.24 Action of the iris in bright light

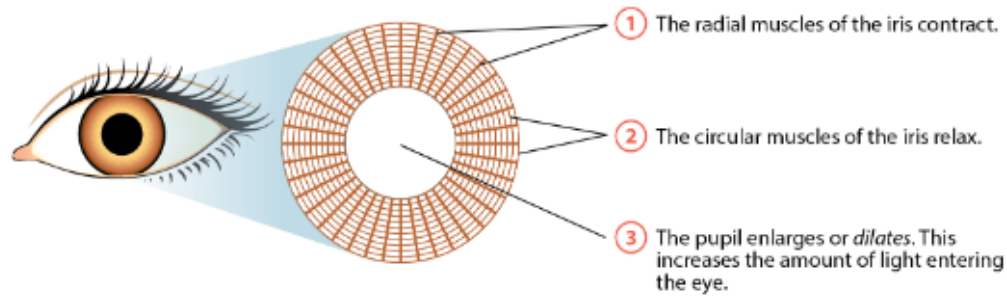


Figure 10.25 Action of the iris in dim light

You may recall that in any reflex action, there must be a receptor and an effector. In the pupil reflex, receptors are found in the retina, and the effector is the iris. The reflex arc involved in the pupil reflex is shown in Figure 10.26.

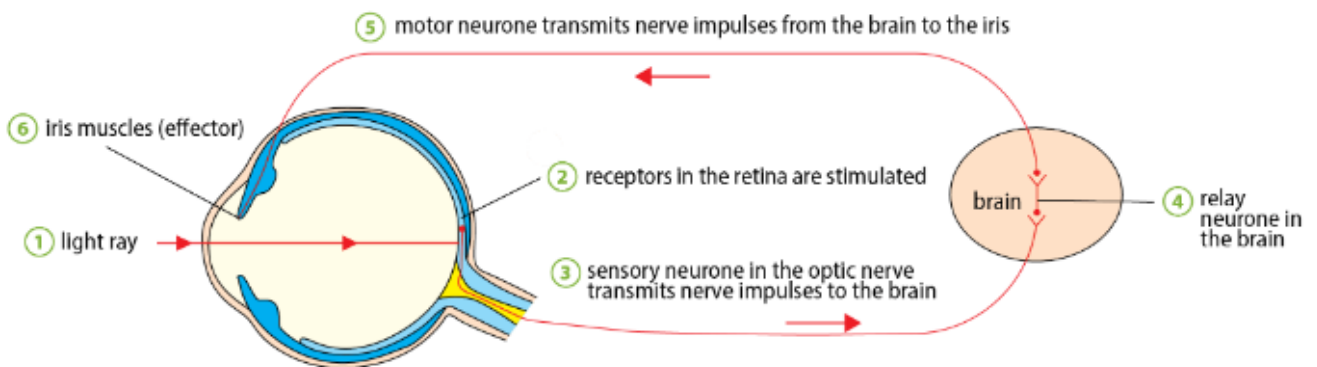
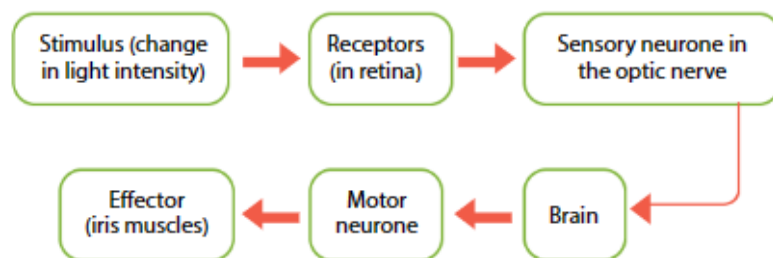


Figure 10.26 Nervous pathway in pupil reflex

The pathway of nerve impulses in the pupil reflex can be summarised as follows:



Let's Investigate 10.2

Aim

To examine the human eye

Procedure

- 1 Use a flat mirror to look at your left eye. Make a drawing of your eye. Label the following: sclerotic coat, iris, pupil and eyelashes.
- 2 Cover your left eye completely with your left hand. Hold the mirror with your right hand. Count to 20 slowly and then immediately remove your left hand from your eye. Look into the mirror to see what happens to the pupil of your left eye. Describe what you see.
- 3 (a) Mark a cross on a piece of paper and add a dot about 8 cm to the right of it.



Figure 10.27

- (b) Hold the paper such that the dot is close to your left eye. Cover your right eye. Keeping the left eye fixed on the dot, move the paper slowly away from the eye. Describe what you see.

Questions

- 1 Explain your observations in **steps 2** and **3**.
- 2 What is the reflex action that takes place in **step 2**? Name the stimulus and the effector in this reflex action.



Link

Practical Workbook
Experiment 10A



Link

Theory Workbook
Worksheet 10B

Let's Practise 10.2

- 1 State briefly the function of each of the following structures in the eye:
 - (a) cornea
 - (b) fovea
 - (c) pupil
 - (d) iris
- 2 Which region of the eye causes the greatest refraction of light into the eye?
- 3 How does pupil reflex benefit the eye?

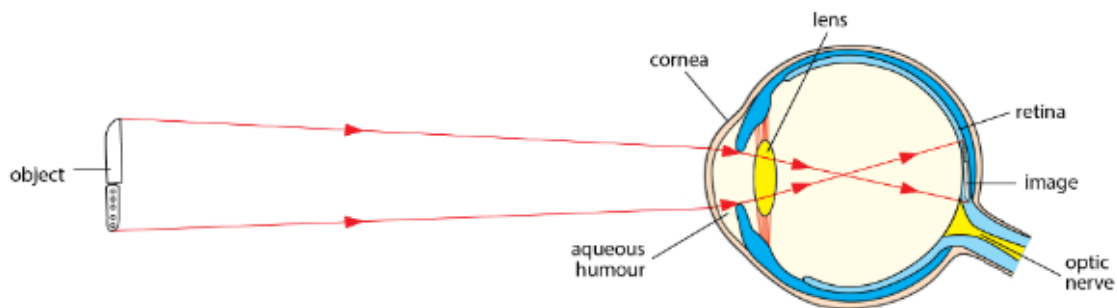
10.3 How Do We See?

Learning Outcome

- State the principal functions of component parts of the eye in producing a focused image of near and distant objects on the retina.

Cameras, telescopes and binoculars rely on reflected light rays going through a lens to produce an image. Our eyes work using this same principle.

When light falls on an object, rays of light are reflected from the object. Some of these reflected rays fall on the eye (Figure 10.28).



- ① The light rays are refracted through the cornea and the aqueous humour onto the lens.
- ② The lens causes further refraction and the rays are brought to a focus on the retina.
- ③ The image on the retina stimulates either the rods or the cones, depending on the intensity of the light. The image formed on the retina is:
 - upside down (Inverted)
 - laterally inverted
 - diminished (smaller in size than the actual object)

Figure 10.28 Formation of an image on the retina

Nerve impulses are produced when light falls on the rods and cones. These nerve impulses are transmitted via the optic nerve to the brain. The brain interprets these nerve impulses so that we see the object the right way up, front to back, and the right size.



What Is Focusing?

- **Focusing**, also called **accommodation**, is the adjustment of the lens of the eye so that clear images of objects at different distances are formed on the retina.

Focusing is necessary so that objects at different distances can be seen clearly. In focusing, the thickness or curvature of the lens is adjusted. This allows light rays to be focused on the retina.



Link

Physics

In Physics, we learn about the formation of images by a thin converging lens.

Focusing on a Distant Object

When a person is looking at a distant object (estimated at 7 m or more), the light rays reflecting off the object are almost parallel to each other when they reach the eye. These light rays are then refracted through the cornea and the aqueous humour into the pupil. Since the rays are almost parallel, the lens needs to be thinner as only a little refraction is needed.

Figure 10.29 shows how the eye is focusing on a distant object.

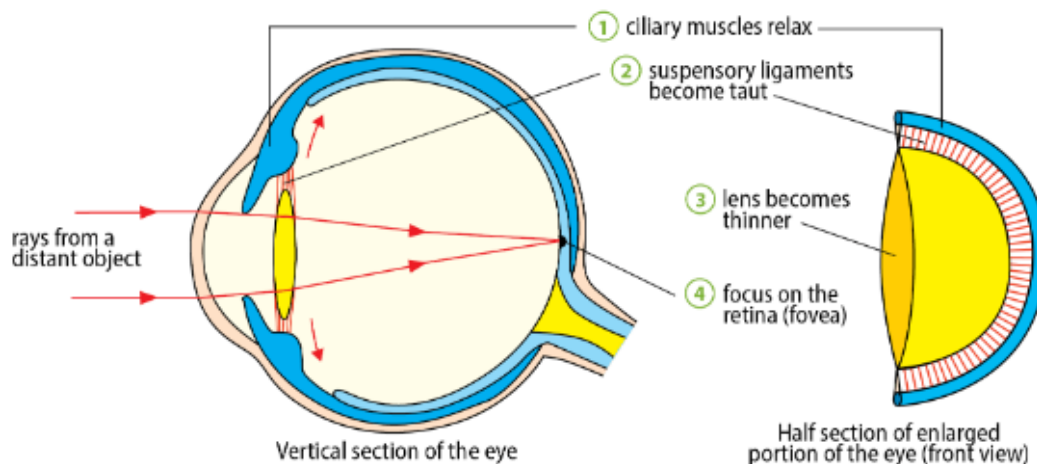


Figure 10.29 Focusing on a distant object

The following changes occur in the eye when focusing on a distant object:

- 1 Ciliary muscles relax, pulling on the suspensory ligaments.
- 2 Suspensory ligaments become **taut**, pulling on the edge of the lens.
- 3 Lens becomes thinner and less convex.
- 4 Light rays from the distant object are sharply focused on the retina.
- 5 Photoreceptors are stimulated.
- 6 Nerve impulses produced are transmitted by the optic nerve to the brain. The brain interprets the nerve impulses, and the person sees the distant object.



Word Alert

Taut: tight



Focusing on a Near Object

When a person is looking at a near object (e.g. when reading a book), diverging light rays reflecting off the near object are refracted through the cornea and the aqueous humour into the pupil. Since the rays reaching the eye are diverging, the lens needs to be thicker (i.e. more convex) to bend the light rays more.

Figure 10.30 shows how the eye is focusing on a near object.

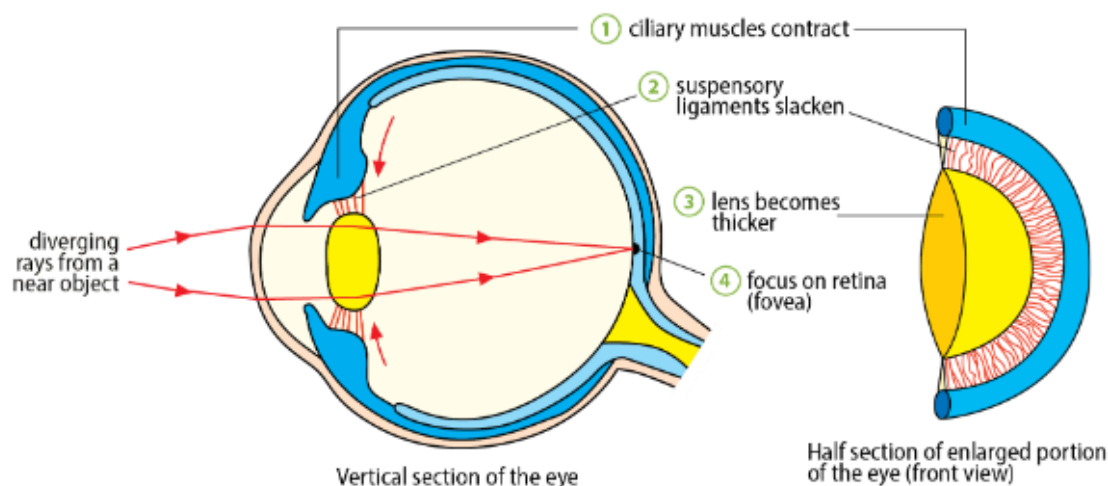


Figure 10.30 Focusing on a near object

The following changes occur in the eye when focusing on a near object:

- 1 Ciliary muscles contract, relaxing their pull on the suspensory ligaments.
- 2 Suspensory ligaments **slacken**, relaxing their pull on the lens.
- 3 The lens, being elastic, becomes thicker and more convex.
- 4 Light rays from the near object are sharply focused on the retina.
- 5 Photoreceptors are stimulated.
- 6 Nerve impulses produced are transmitted by the optic nerve to the brain. The brain interprets the nerve impulses, and the person sees the near object.



Word Alert

Slacken: relax, become looser



Link

Theory Workbook
Worksheet 10C
Let's Assess
Let's Reflect

Let's Practise 10.3

- 1 (a) State the process by which images of objects of different distances from the eye are focused on the retina.
- (b) Describe how the process in (a) is achieved when a person looks from a nearby object to a distant object.

Let's Map It

The Nervous System

is made up of

Central nervous system (CNS)

Peripheral nervous system (PNS)

consisting of the

consisting of the

Brain

Spinal cord

Receptors

Nerves

- Controls voluntary actions by generating nerve impulses
- Controls cranial reflexes (e.g. salivation)

- Transmits nerve impulses to and from the brain
- Controls spinal reflexes (e.g. knee-jerk reflex)

- Cranial nerves:
- Sensory nerves transmit nerve impulses from receptors to brain
 - Motor nerves transmit nerve impulses from brain to effectors

- Spinal nerves:
- Sensory nerves transmit nerve impulses from receptors to spinal cord
 - Motor nerves transmit nerve impulses from spinal cord to effectors

made up of

Nervous tissue

consisting of

Neurones

of three types

- Sensory (receptor) neurone
- Relay (intermediate) neurone
- Motor (effector) neurone

found in sense organs such as

which detect stimuli and produce

Nerve impulses

which transmit

which travel along a particular nervous pathway, such as the

Reflex arc

Receptor

Sensory neurone

Relay neurone (in the CNS)

Motor neurone

Effector

which responds to light by the

Pupil reflex

which can adjust focus for viewing distant and near objects by

Focusing or accommodation

In bright light:

- Circular muscles of the iris contract
- Radial muscles of the iris relax
- The pupil becomes smaller; hence, less light enters the eye

In dim light:

- Circular muscles of the iris relax
- Radial muscles of the iris contract
- The pupil becomes larger; hence, more light enters the eye

Focusing on distant objects:

- Ciliary muscles relax
- Suspensory ligaments become taut
- The lens becomes thinner and less convex

Focusing on near objects:

- Ciliary muscles contract
- Suspensory ligaments slacken
- The lens becomes thicker and more convex

Let's Review

Section A: Multiple-choice Questions

1 Which of the following pathway of a nerve impulse is **correct**?

- ☐ A Brain → spinal cord → motor neurone → receptor
- ☐ B Brain → spinal cord → motor neurone → effector
- ☐ C Effector → motor neurone → CNS → sensory neurone → receptor
- ☐ D Receptor → motor neurone → CNS → sensory neurone → effector

2 Which of the following is **not** an example of a reflex action?

- ☐ A Eye blinking
- ☐ B Mouth salivating
- ☐ C Hand waving at a friend
- ☐ D Pupil of the eye becoming smaller

3 A man saw a bus approaching from a distance. He looked at his watch. He then saw his friend across the street and waved to him. Which of the following shows the order of changes of the shape of the lens in his eye?

- ☐ A  ☐ B 
- ☐ C  ☐ D 

4 A reflex action involves a receptor and an effector. Which of the following shows the structure where the receptor is found and the effector when the pupil of the eye constricts?

	Structure Where Receptor Is Found	Effector
☐ A	fovea	ciliary muscles
☐ B	fovea	iris muscles
☐ C	pupil	ciliary muscles
☐ D	pupil	iris muscles

Section B: Structured Questions

1 Figure 10.31 shows a simple spinal *reflex arc*.

- (a) Explain what a *reflex arc* is.
- (b) Name the structures labelled A to E through which the nerve impulses travel.

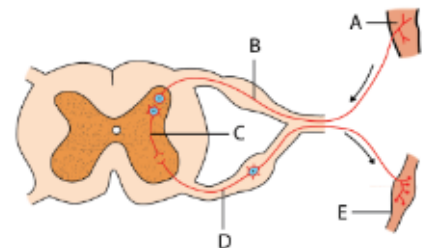


Figure 10.31

2 Figure 10.32 shows how three different persons have their nervous systems blocked at three different places by a local anaesthetic.

- Person A: blocked at X
- Person B: blocked at Y
- Person C: blocked at Z

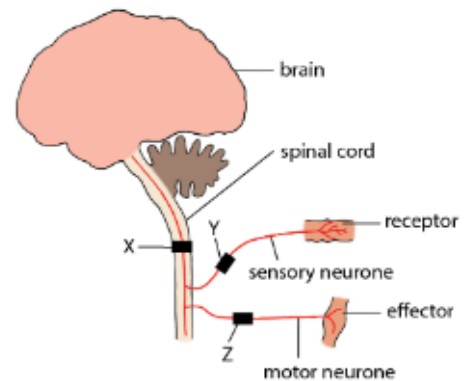


Figure 10.32

- (a) Which person can consciously and voluntarily move his arm but cannot feel a pinprick on his arm? Explain.
- (b) Which person can respond to a pinprick on his arm but cannot feel it? Explain.
- (c) Which person can feel a pinprick on his arm but cannot move his arm? Explain.

- 3 Figure 10.33 shows a section of the eye of a person who is looking at a distant object.

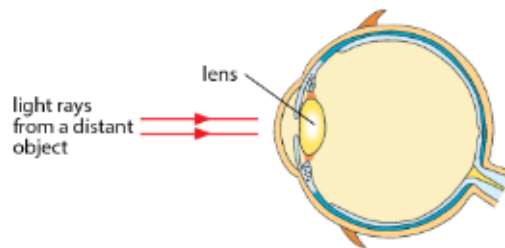


Figure 10.33

- (a) Explain how the eye enables the person to see.
- (b) Name and label the structure that:
 - (i) controls the amount of light entering the eye
 - (ii) alters the shape of the lens
 - (iii) prevents internal reflection of light

Section C: Free-response Questions

- 1 An ant bites your leg, and you can feel the pain. State the routes through which nerve impulses would travel in order for you to feel the pain.

- 2 (a) What is *focusing* or *accommodation*?
 (b) Suppose you are sitting outdoors under an umbrella and reading a book. You suddenly look up at the sky to see an aeroplane fly past. Explain the sequence of events in your eyes that enable you to see both the printed page in your book and the aeroplane.

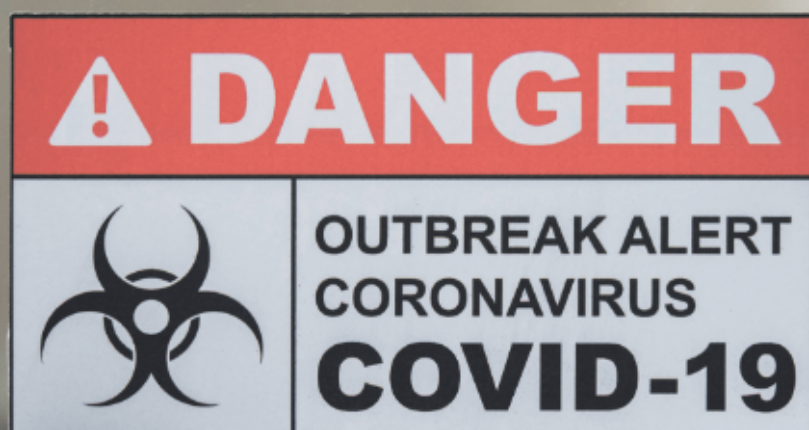
- 3 Describe the nervous pathways and reactions involved when a bright light is suddenly shone into the eye.
- 4 As a person grows older, the lens in each of his eyes may become cloudy or opaque. These cloudy areas are called cataracts. Suggest how cataracts might affect the ability of the lens to carry out its functions.
- 5 Do you agree with the following?
"One set of muscles controls the thickness of the lens while two sets of muscles control the size of the pupil in the eyeball."

Explain your answer.

CHAPTER

11

Infectious Diseases in Humans



What You Will Learn



- What are infectious diseases?
- What are the structures of a bacterial cell and a virus?
- How can infectious diseases be prevented and managed?

In March 2020, the World Health Organisation declared Coronavirus Disease 2019 (COVID-19) a global pandemic. A pandemic is the worldwide spread of a new disease. COVID-19 spread quickly in many countries and the number of global deaths increased rapidly. Governments had to act quickly to contain the spread of the infectious disease.



Singapore had encountered infectious disease outbreaks such as Severe Acute Respiratory Syndrome (SARS) in 2003 and swine flu (H1N1) in 2010. This meant that measures were already in place to help contain the spread of COVID-19. These measures included the establishment of government quarantine (isolation) facilities and a national centre for infectious diseases.

In this chapter, you will find out how some infectious diseases are spread and what measures are needed to contain them.

11.1 What Are Infectious Diseases?

Learning Outcomes

- State that infectious diseases can be spread from person to person whereas non-infectious diseases cannot and identify examples of each.
- Explain that infectious diseases are caused by pathogens such as bacteria and viruses and can be spread from person to person through body fluids, food and water.

Think of a time when you were sick. Falling sick is not a pleasant experience. Often you can tell when you are not feeling well. What signs and/or symptoms did you have?

Every year, many people around the world fall ill with signs and symptoms of the flu, such as fever, cough, fatigue and muscle aches. Do these signs and symptoms seem familiar to you?

The flu is the commonly used name for a disease known as influenza. While it is quite easy to obtain medicines to treat the flu, research is still being conducted to develop treatments for many other diseases. What is a disease and why is it important to study diseases?

A **disease** is a condition that causes the body to function less effectively. Diseases produce specific signs or symptoms.

A sign of a disease can be observed or measured. Examples of signs are rashes, fever, coughing and vomiting (Figure 11.1). A symptom of a disease can be described or felt by the patient. Examples of symptoms are headaches, fatigue and nausea.



Figure 11.1 Coughing can be a sign of a disease.

Infectious and Non-Infectious Diseases

Infectious or transmissible diseases can be spread from one person to another. They are caused by disease-causing organisms called **pathogens**. Examples of pathogens include bacteria and viruses. Influenza, HIV and pneumococcal disease are some examples of infectious diseases.

Non-infectious diseases are not caused by pathogens. These diseases cannot spread from one person to another. They may be inherited or may be caused by factors such as malnutrition, environmental factors (e.g. pollution) and lifestyle choices. For example, excessive alcohol consumption may cause liver cirrhosis and excessive consumption of polyunsaturated fats and trans fats may cause coronary heart disease (Figure 11.2). Cigarette smoking may cause atherosclerosis and coronary heart disease. Other non-infectious diseases include type 2 diabetes and sickle cell anaemia.

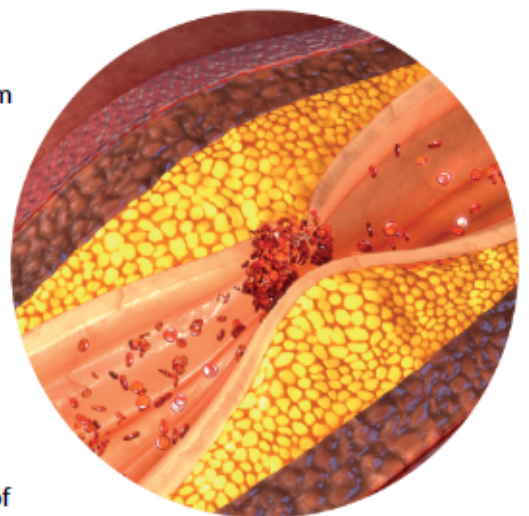


Figure 11.2 Coronary artery partly blocked by fatty deposits on its inner surface

How Are Infectious Diseases Spread?

Diseases can spread from person to person through several ways.

Through Droplets in the Air

When a person coughs or sneezes, numerous tiny respiratory droplets are expelled. These droplets may contain pathogens. Anyone within a close range (about 1 m) may breathe in these droplets and become infected. During a disease **outbreak**, people are advised to wear a mask and exercise social distancing. How can this protect us from pathogens?

How can we show social responsibility to protect ourselves and others during a disease outbreak? During the COVID-19 pandemic, wearing a face mask when in public was compulsory in many countries. However, in other countries, this was optional. Can you think of reasons why some people may not want to wear a mask?

By Direct Contact

Some diseases are spread through direct contact. For example, an infected person may infect another person by exchanging body fluids during sexual intercourse. Sexually Transmitted Infections (STIs) such as the Human Immunodeficiency Virus (HIV) can be transmitted in this way. Some diseases, such as hepatitis B and syphilis, can also be transmitted from mother to baby through breastfeeding.

Infectious diseases can also be spread when blood from an infected person comes into contact with:

- the mucous membranes (e.g. membranes lining the eye, nose and mouth) of an uninfected person, or
- the bloodstream of an uninfected person, such as through a break in the skin

By Contaminated Food and Water

Food and water can be contaminated with pathogens such as bacteria that cause a disease known as cholera (Figure 11.3). This can occur when food and water are not properly stored or handled. Methods to prevent and control the spread of **water-borne and food-borne diseases** include:

- practising hygienic food preparation and storage
- having good personal hygiene
- maintaining a clean water supply
- ensuring proper sewage treatment

Figure 11.3 Houseflies can deposit pathogens onto our food.



Word Alert

Outbreak: a sudden breaking out of something unpleasant, such as disease or war



Word Alert

Water-borne and food-borne diseases: diseases carried or transmitted by contaminated food and water



Look at Figure 11.4. Give your views on the statements made about wearing masks during an outbreak of an infectious disease, such as COVID-19.



Figure 11.4 Three teenagers are discussing whether masks should be worn during an outbreak of an infectious disease, such as COVID-19. Do you agree? Why or why not?



Helpful Note

Figure 11.5 shows how droplets of moisture are expelled during coughing.



Figure 11.5 Coughing introduces droplets of moisture into the air.

Wearing masks can help minimise the spread of diseases (Figure 11.6). Masks can help reduce the likelihood and severity of transmission by reducing the amount of pathogens released from a person into the air. Wearing masks can also reduce the chance of getting infected by a pathogen. Cotton masks, surgical masks and N95 masks reduce transmission of pathogens through respiratory droplets.

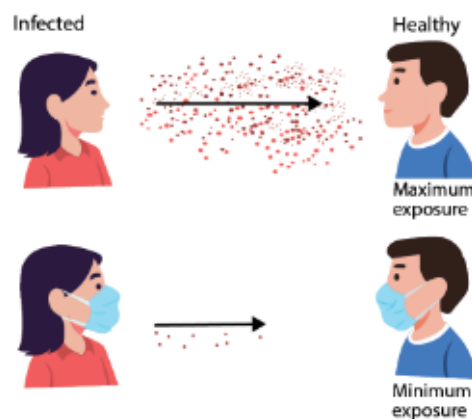


Figure 11.6 The use of masks cuts down on the spread of pathogens via droplets.



Link

Practical Workbook
Experiment 11A



Tech Connect

We expel droplets through our nose and mouth when we cough or sneeze. Did you know that we also expel droplets when we talk?

Some small particles, such as droplets of water vapour, can be seen using laser light scattering equipment (Figure 11.7). In fact, scientists have conducted a study which showed that the louder a person spoke, the more droplets were expelled from his or her mouth.

What implications do the results of this study have on how diseases are spread? What precautions should we take to contain diseases?

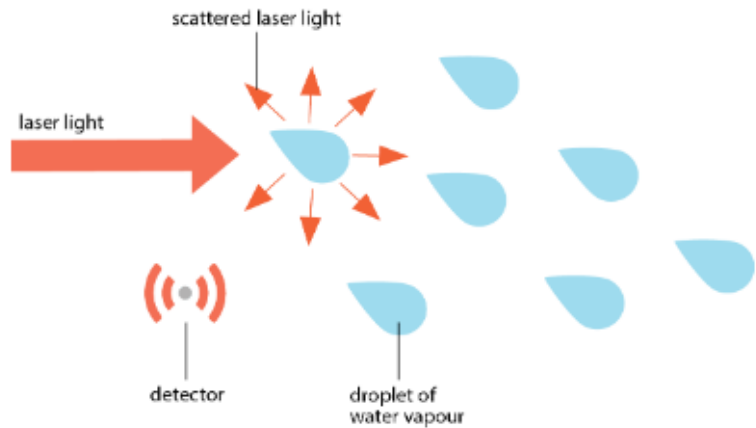


Figure 11.7 When a laser light is shone onto a particle, it interacts with the particle and is scattered in a way that is characteristic of the particle size.



Tech Connect

During the COVID-19 outbreak, governments collected and used data to help contain the spread of the disease. In Singapore, the government created a mobile application called “TraceTogether”. This application uses Bluetooth technology to estimate the distance between two devices. This allowed the government to quickly trace people who had been near a COVID-19 patient. The data collected helps scientists to study important patterns of how the disease has spread in the community. These experts use complex mathematical formulas to analyse the data and give the authorities important insights on how to prevent the spread of the disease in the community.

In addition, wearable devices (Figure 11.8) were also used to help in contact tracing. Why was a wearable device developed when there was already a mobile application?

Do you think we can trace the infection to the very first patient? What other useful data can be gathered using technology to reduce the spread of infectious diseases?



Figure 11.8 Wearable TraceTogether device and mobile phone application



Link

Theory Workbook
Worksheet 11A

Let's Practise 11.1

- 1 Name **two** ways that infectious diseases can be spread from one person to another.
- 2 A man is preparing food in a canteen. He wears a mask and gloves.
 - (a) Suggest why it is important for the man to wear a mask and gloves.
 - (b) Identify the method of transmission that is reduced.

11.2 What Are the Structures of a Bacterial Cell and a Virus?

Learning Outcomes

- State that a typical bacterial cell has a cell wall and DNA without a nucleus; some are pathogenic and some non-pathogenic.
- State that a typical virus has a protein coat enclosing its genetic material and reproduces only in living host cells.



Helpful Note

Many strains of bacteria are harmless. Some are beneficial, such as those that help in digestion and produce vitamins in our body. Harmful bacteria include those that can cause pneumonia or meningitis. The bacteria *Helicobacter pylori* causes gastric ulcers.

Structure of a Bacterial Cell

Bacteria (singular: bacterium) are single-celled organisms (Figure 11.9). A bacterial cell does not have a membrane-bound nucleus. It has a single circular DNA as its genetic material. A bacterial cell also has a cell wall, ribosomes, small circular DNA molecules called plasmids and may have one or more flagella (singular: flagellum). Some bacteria are pathogenic (disease-causing) and some are non-pathogenic (non disease-causing).

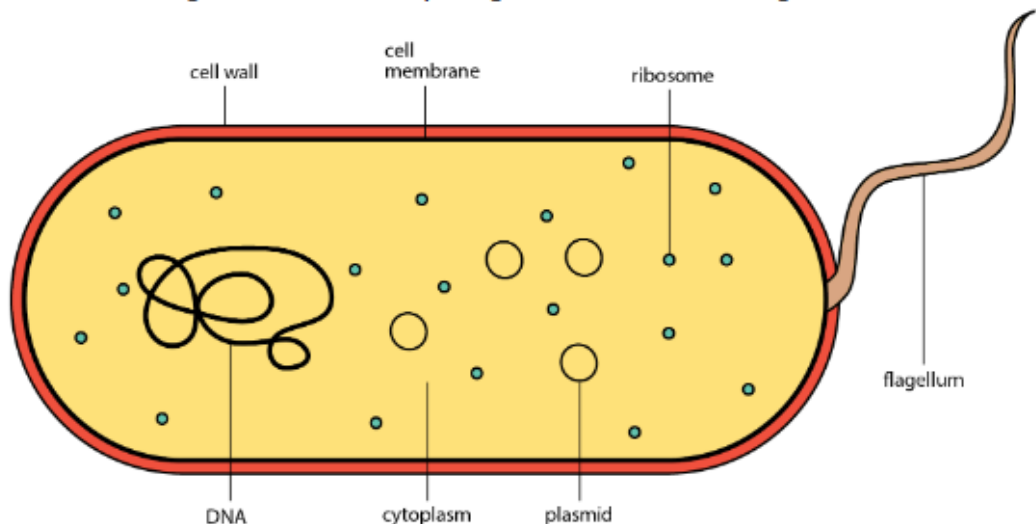


Figure 11.9 Section of a bacterial cell

Structure of a Virus

A typical virus has a protein coat enclosing its genetic material, which is either DNA or RNA (Figure 11.10).

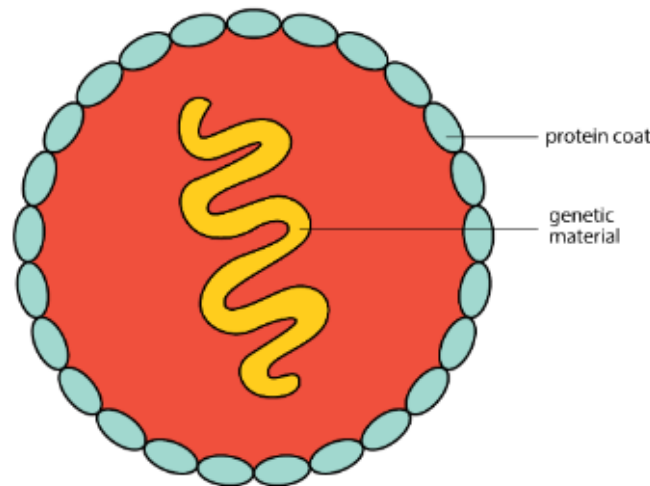


Figure 11.10 Section of a typical virus

A virus has both living and non-living characteristics. A virus does not have cellular structures, such as a cell membrane, cytoplasm or organelles. Unlike living things, it does not grow, move, feed, respire or excrete. However, it can reproduce, but only when it enters a living cell, which acts as a host. This is because the host cell contains the necessary materials for reproduction, such as enzymes, and organelles like ribosomes.

Observe Figures 11.9 and 11.10 carefully. What are the differences between a bacterial cell and a virus? Compare your answers with Table 11.1.

Table 11.1 Comparison of features of a bacterial cell and a virus

Feature	Bacterial Cell	Virus
Outer covering	Cell wall	Protein coat
Genetic material	DNA	DNA or RNA
Cell membrane	Present	Absent
Cytoplasm	Present	Absent
Ribosome	Present	Absent

Let's Practise 11.2

- How does the structure of a virus differ from a bacterial cell?
- Two students are studying the structure of a pathogen. The pathogen has a protein coat, DNA for its genetic material and no ribosomes. Student A concluded that the pathogen is a virus, while student B concluded that it is a bacterial cell.
 - Which student made the correct conclusion?
 - Give reasons for your answer in (a).



Link

Find out about DNA and RNA in Chapter 14.



Helpful Note

As viruses display characteristics of both living and non-living things, most biologists classify them as being somewhere between living things and chemicals.



Link

Theory Workbook
Worksheet 11B

11.3 How Can Infectious Diseases Be Prevented and Managed?

Learning Outcomes

- State the signs and symptoms of:
 - influenza, which is caused by the influenza virus.
 - pneumococcal disease, which is caused by the bacteria, pneumococcus.
- Describe the transmission and methods to reduce the transmission of:
 - influenza virus;
 - pneumococcus.
- State that vaccines contain an agent that resembles a pathogen and prevent infectious diseases by stimulating white blood cells to quickly produce antibodies when the pathogen invades.
- Explain that antibiotics target bacteria by preventing synthesis of cellular structures but are ineffective against viruses due to structural and reproductive differences.
- Discuss how the misuse and overuse of antibiotics may accelerate the emergence of antibiotic-resistant bacteria.

When we are sick, we are not able to function as well as normal. Illness costs us time and productivity. How much better would life be if we could avoid falling sick? Influenza and pneumococcal disease are two common examples of infectious diseases. These infectious diseases, though treatable, can lead to complications that result in death. How can these diseases be prevented and managed?



Link

Recall what you have learnt about respiration in Chapter 7.



Helpful Note

Spike proteins are projections on the surface of the virus. They play an important role in how viruses infect their hosts. The spike proteins latch the virus onto a cell, allowing it to gain entry into the cell.

Influenza

Influenza, or flu, is a disease that attacks the respiratory system. Most people recover from this disease within two weeks. However, at times, influenza can lead to complications such as pneumonia (lung infection). Influenza is caused by the influenza virus (Figure 11.11).

- Cause:
 - Influenza is caused by the influenza virus (Figure 11.11).
- How it is transmitted:
 - Influenza is transmitted through droplets in the air and when a person touches an object or a surface contaminated with the virus and then touches his or her own mouth, nose or eyes.
- Signs and symptoms:
 - Influenza produces signs and symptoms such as high fever, headache, stuffy nose, cough, sore throat and muscle aches.

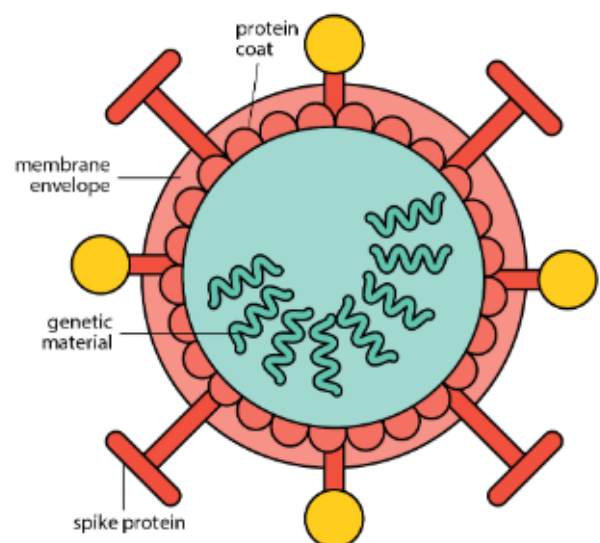


Figure 11.11 Section of an influenza virus

Methods to Reduce Transmission of the Influenza Virus

- 1 Get the influenza vaccination. An annual vaccination is recommended.
- 2 Avoid coming into close contact with people who have the flu. If you are sick, keep your distance from others to prevent them from getting infected too.
- 3 If you are sick, cover your mouth and nose with a tissue when you cough or sneeze and dispose of the used tissue properly. This will help to prevent the spread of the flu to others around you. Wear a surgical mask if you are not feeling well.
- 4 Wash your hands with soap and water or rub with disinfectant if you think you have touched objects that are likely to be contaminated with the virus (Figure 11.12). Using hand sanitisers is an effective way to disinfect your hands.
- 5 As far as possible, avoid touching your eyes, nose and mouth. Viruses are often spread when a person touches something that is contaminated with viruses that cause flu and then touches his or her eyes, nose or mouth.
- 6 Take antiviral drugs as prescribed by the doctor to treat the illness.



Figure 11.12 Washing or disinfecting our hands can help reduce the transmission of viruses.



Link

Chemistry

We learn that alcohol can be a disinfectant.



Link

Practical Workbook
Experiment 11B

Pneumococcal Disease

Pneumococcal disease is one of the major causes of death worldwide. It is caused by pneumococcus bacteria, also known as *Streptococcus pneumoniae* (Figure 11.13). The bacteria may attack different parts of the body. For example, they may cause middle ear infection, lung infection (pneumonia), inflammation of the membranes of the brain and spinal cord, and infection of the blood.

- Cause:
 - Pneumococcal disease is caused by pneumococcus bacteria, also known as *Streptococcus pneumoniae* (Figure 11.13).
- How it is transmitted:
 - It is mainly transmitted through respiratory droplets.
- Signs and symptoms:
 - Fever, headache, vomiting, cough, chest pain and rapid breathing

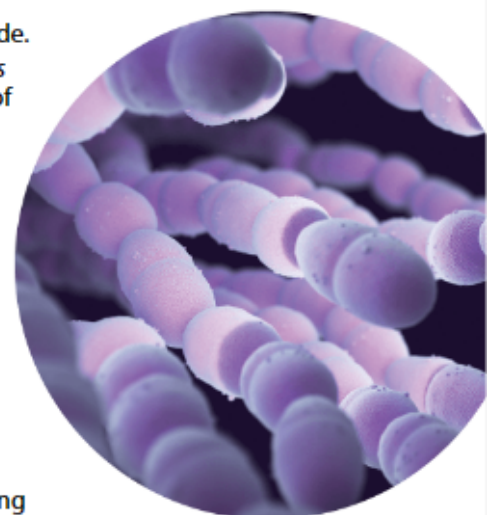


Figure 11.13 *Streptococcus pneumoniae*

Methods to Reduce Transmission of Pneumococcus Bacteria

- 1 Get the pneumococcal vaccination.
- 2 Take daily preventive actions (refer to points 2–5 for influenza).
- 3 Take antibiotics as prescribed by the doctor to treat the disease.

Vaccines

One way to protect ourselves from diseases such as influenza and pneumococcal disease is by receiving a vaccine. What exactly is a vaccine and how does it protect us from a disease?

- ▶ A **vaccine** contains an agent that resembles a pathogen and prevents infectious diseases by stimulating white blood cells to quickly produce antibodies when the pathogen invades.

The process of receiving a vaccine is known as **vaccination** (Figure 11.14).

In Singapore, it is compulsory for children to be vaccinated against serious infectious diseases like diphtheria and measles. Some diseases require a second dose of the vaccine called a booster to keep the body protected against the disease.

Some vaccines are taken orally, while others are administered through an injection.



Figure 11.14 Many vaccinations are administered through an injection.



Past to Present

In the 1600s, smallpox was known as a deadly disease. Those who suffered from the disease developed severe, unsightly sores (Figure 11.15). Survivors were left with permanent scars.

In 1796, an English doctor called Edward Jenner noted that milkmaids who had previously been infected with cowpox did not get smallpox. He conducted a risky experiment by injecting the fluid taken from a milkmaid's cowpox sore into a young boy. This young boy was later exposed to the smallpox virus but did not develop the disease. This marked the beginning of the smallpox vaccine, the first vaccine to completely eliminate an infectious disease.

Do you think Jenner was justified in exposing the boy to the smallpox virus? When is taking risks appropriate and justified?

Jenner's theory on cowpox and smallpox was initially not accepted. What evidence do you think he needed to present for his theory to be accepted? Over the past 20 years, advancements in research and technology have played an important role in the development of vaccines. Some successes include the development of hepatitis B vaccines and new techniques to manufacture vaccines for the seasonal flu.

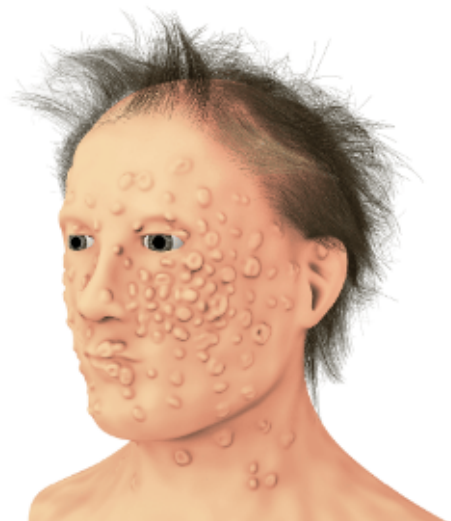


Figure 11.15 Illustration of smallpox sores

How Vaccines Work

Substances that can trigger the production of antibodies are called **antigens**. When foreign particles such as pathogens enter our bloodstream, they stimulate our white blood cells to produce antibodies against them. Proteins on the surfaces of pathogens, such as bacteria and viruses, are examples of antigens. When a vaccine, which contains an agent that resembles a pathogen (antigen), enters the body, it stimulates the white blood cells to produce **antibodies** (Figure 11.16). Antibodies are proteins that are produced to destroy a pathogen. They are specific in action. Antibodies that destroy one type of pathogen will be ineffective against another type of pathogen. Antibodies can also tag a pathogen for destruction by white blood cells.



Helpful Note

Some white blood cells remain in the bloodstream for a long time, and are known as memory cells. These memory cells give long-term protection against a pathogen. In the future, when the same pathogen enters the body, the memory cells in the bloodstream can recognise it and divide quickly to produce large numbers of antibodies. The antibodies will then destroy the pathogen before it has a chance to cause the disease.

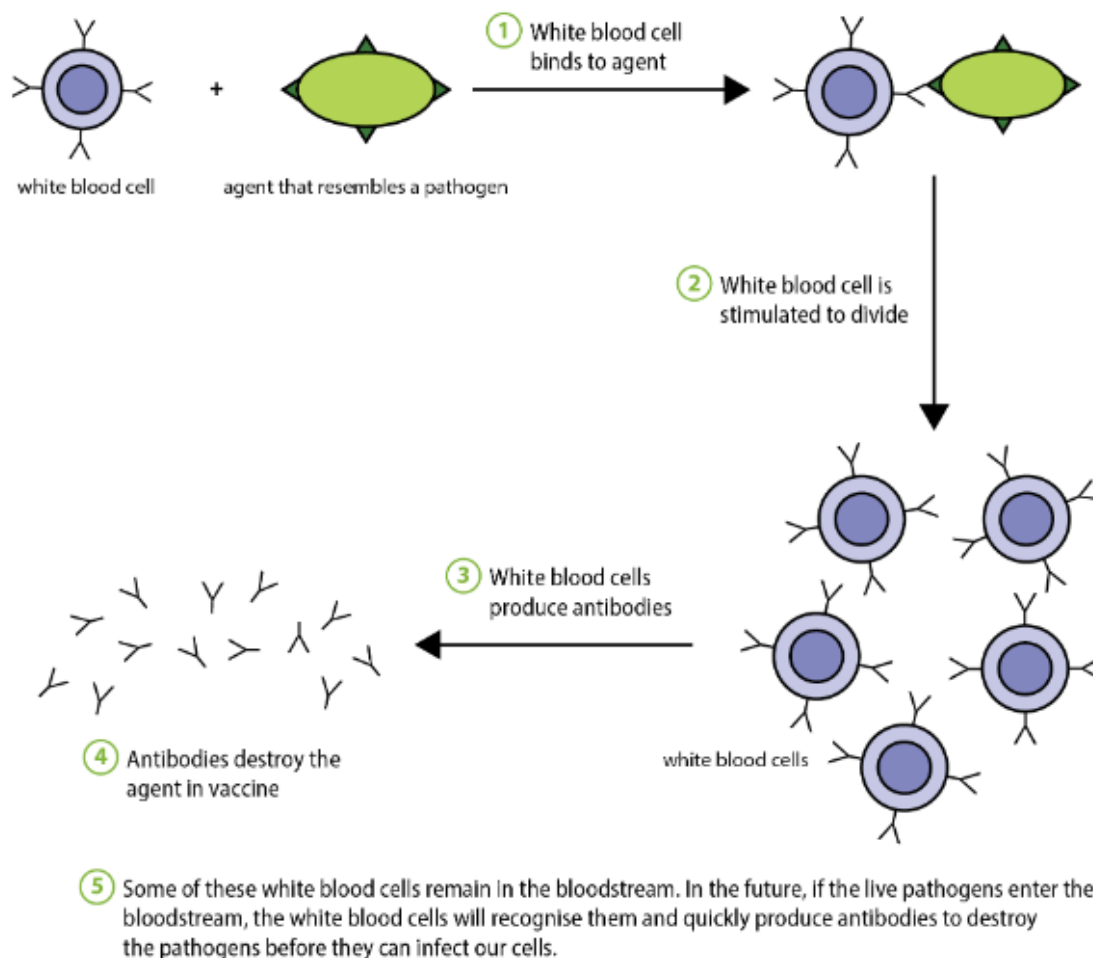


Figure 11.16 How a vaccine works

After we have recovered from an influenza infection, we are protected from another influenza infection. Yet, a few months later we may get infected by the same virus again. Can you think of a reason why?



Past to Present

A significant milestone in medical history was reached in 1928 by Alexander Fleming, who made an accidental discovery. He noticed that the bacteria culture he had grown had been contaminated with mould. In addition, the bacteria surrounding the mould had been destroyed. Named *Penicillium notatum* (Figure 11.17), this mould was used to isolate penicillin, the world's first antibiotic.

Fleming's curiosity led him to investigate further.



Figure 11.17 *Penicillium notatum* fungi



Link

Recall what you have learnt about osmosis in Chapter 2.

Antibiotics

Have you ever been prescribed antibiotics by your doctor? The doctor may have reminded you to complete the full course, even if you started feeling better. What are antibiotics and why is it so important to complete the course?

Antibiotics are drugs used to treat bacterial infections. They are made by microorganisms and are used to kill or inhibit the growth of bacteria. They work by interfering with the growth and metabolic activities of the bacteria. *Antibiotics are ineffective against viruses.* Many antibiotics are chemically modified to make them more effective in treating diseases.

How Do Antibiotics Work?

Figure 11.18 shows how antibiotics act on a typical bacterial cell.

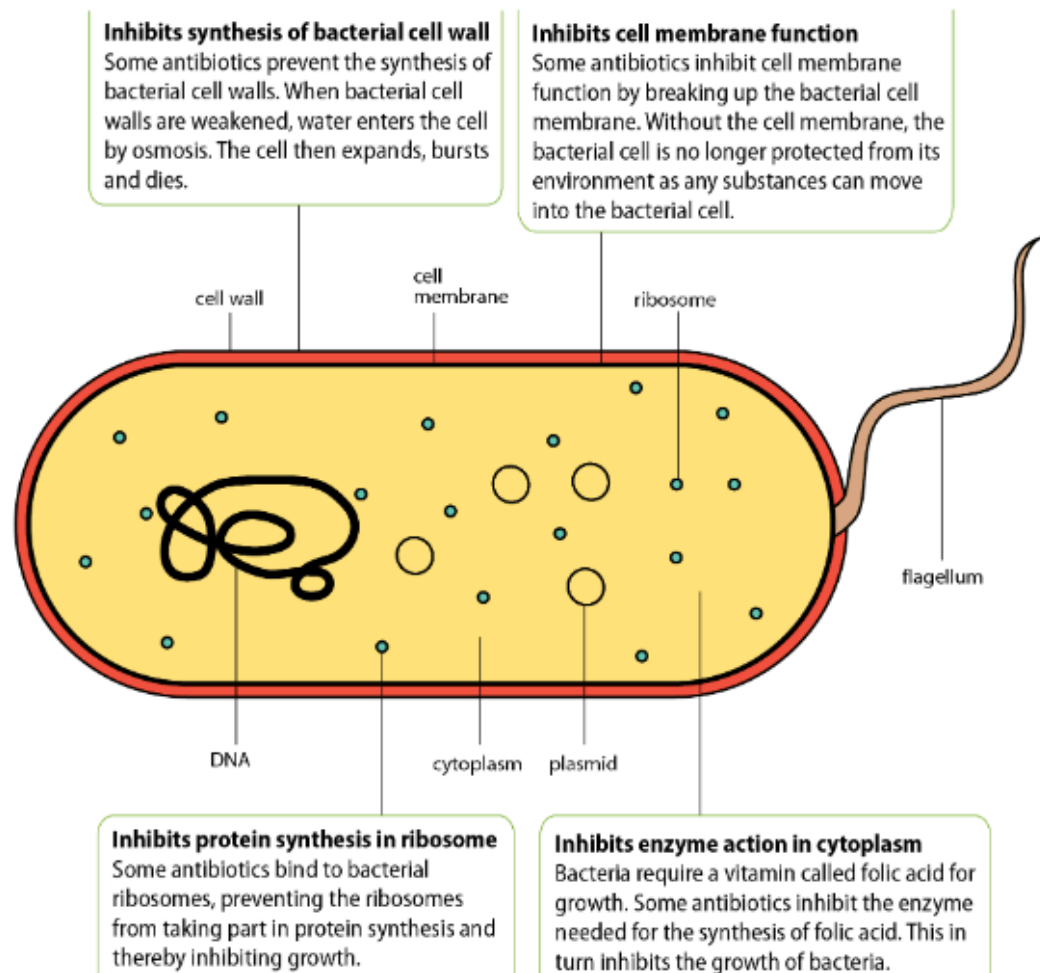


Figure 11.18 How antibiotics work to destroy a bacterial cell

Why Antibiotics Can Kill Bacteria but Not Viruses

Antibiotics can be administered in different forms to kill bacteria. However, antibiotics are ineffective against viruses. Why do you think that is?

Recall the differences between the structures of bacteria and viruses.

Antibiotics are ineffective against viruses for the following reasons:

- They act on bacterial cell walls. Viruses do not have cell walls.
- They break up cell membranes. Viruses do not have cell membranes.
- They act on ribosomes, inhibiting protein synthesis and growth. Viruses do not have ribosomes and they do not grow.

A person with a viral infection requires rest. With time the body will recover from the infection. The patient can be given antivirals, which are medications that help the body fight off disease-causing viruses.

Let's Investigate 11.1

Aim

To observe the effects of antibiotics on bacteria

Procedure

- 1 The Petri dish in Figure 11.19 contains agar with bacteria growing on it. There are six discs in the Petri dish, and each disc is a different type of antibiotic. Study Figure 11.19 carefully.
- 2 Note the transparent areas around four of the discs. These indicate that the antibiotic has been successful in killing the bacteria.

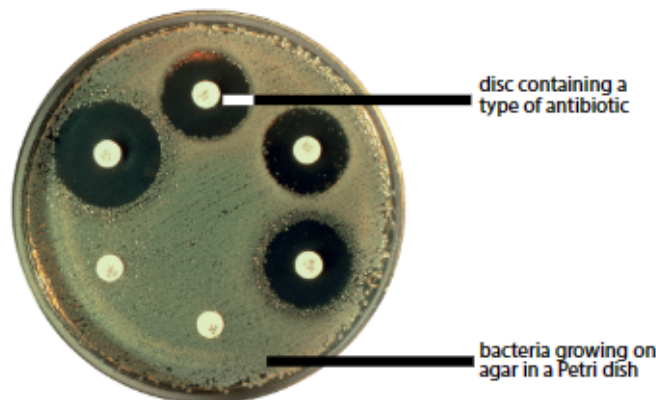


Figure 11.19

Questions

- 1 How can you tell if one antibiotic is more effective than the others?
- 2 How many of the antibiotics are ineffective against the bacteria?
How did you arrive at your answer?

How Does Antibiotic Resistance Come About?

Have you heard of the term “superbugs”? They are bacteria that are resistant to medicines such as antibiotics. How do bacteria develop resistance to antibiotics? Figure 11.20 shows what could happen when an antibiotic, X, is taken to treat a bacterial infection.



Link

Read about mutation in Chapter 18.

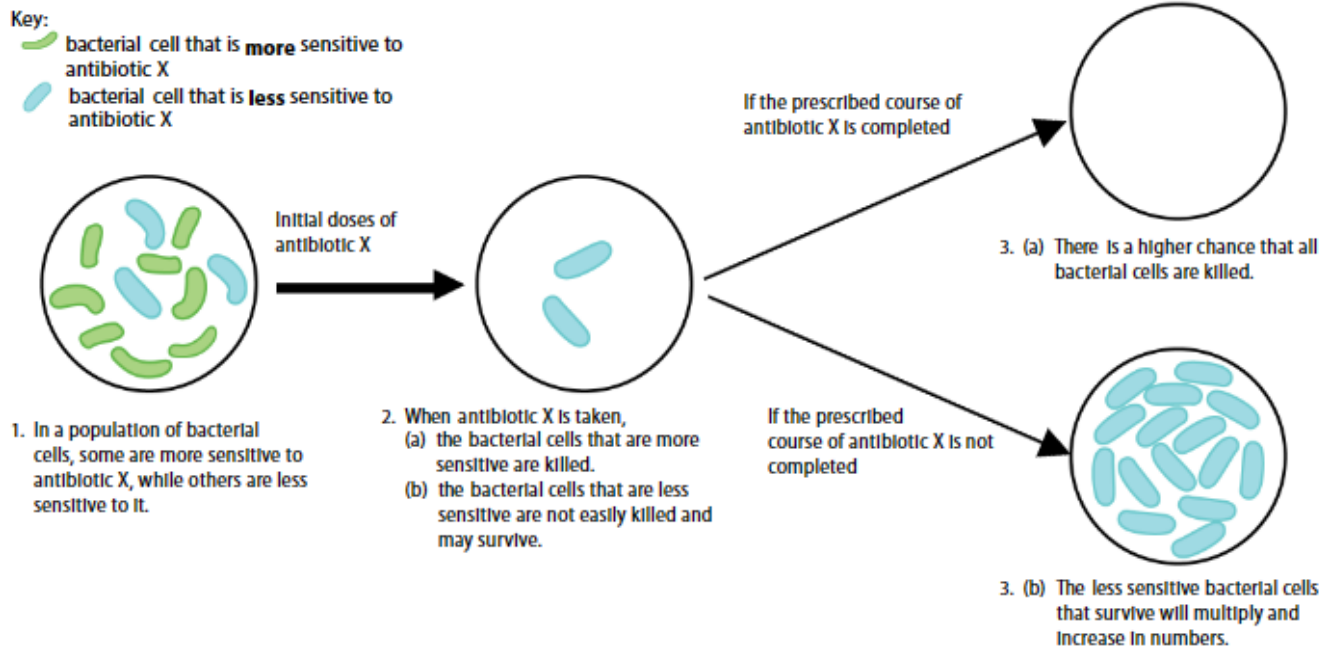


Figure 11.20 Possible outcomes when antibiotic X is taken to treat a bacterial infection



Disciplinary Idea

Evolution

The misuse of antibiotics has resulted in the evolution of antibiotic-resistant bacteria. This is a result of the bacteria adapting to be resistant to current treatments.

Over time, the subsequent generations of bacterial cells will become increasingly less sensitive to antibiotic X. Eventually, the population of bacterial cells becomes resistant to antibiotic X. Antibiotic X will not be able to kill the antibiotic-resistant bacterial cells. Other types of antibiotics will be required to treat the bacterial infection. Hence, to prevent antibiotic resistance in bacteria, a prescribed course of antibiotics should be completed. Antibiotics should also not be used for non-bacterial infections.

How Antibiotic Resistance Can Be Reduced

We can reduce antibiotic resistance in bacteria by:

- not misusing or overusing antibiotics;
- completing the full course of antibiotics prescribed by doctors so that all the bacteria are killed;
- using antibiotics only when necessary.



Link

Theory Workbook

Worksheets 11C–11E
 Let's Assess
 Let's Reflect

Let's Practise 11.3

- 1 (a) State **two** signs and symptoms that are common to influenza and pneumococcal disease.
 (b) How can we prevent the transmission of influenza and pneumococcal disease?
- 2 What does a vaccine consist of?
- 3 Explain why antibiotics are effective against bacteria but not viruses.
- 4 Misuse of antibiotics can lead to antibiotic resistance.
 (a) State **two** ways in which antibiotics are misused.
 (b) Explain what could happen if a full course of antibiotics is **not** completed.



Problem-based Learning Activity

It is the month of December in Singapore. Many people are suffering from the flu, caused by a seasonal strain (type) of the influenza virus. The flu season that has just started seems more serious than any of the flu seasons we have seen in the past. The reason being that this particular virus spreads three times as quickly. The number of flu-related deaths is also higher than in previous years. In a situation like this, scientists often must race against time to develop treatment options (Figure 11.21).

The Ministry of Health has called together a team of experts to study the problem. As a member of the expert team, you are tasked to suggest ways to slow down the spread of the virus. Apply what you know about the influenza virus and how it infects the human body to design ways to solve this problem.

Consider the following questions:

- What data would you need to gather for this task and how would you do it?
- What are the different treatment options? What are some ways to prevent community spread of the virus?
- What recent technologies or innovations are you aware of that can help manage the spread of infection?

Figure 11.21 Scientists must constantly innovate and come up with new medicines and treatment options for infectious diseases.



Link

Theory Workbook
Problem-based Learning:
Application

Practical Workbook
Problem-based Learning:
Suggested STEM Project



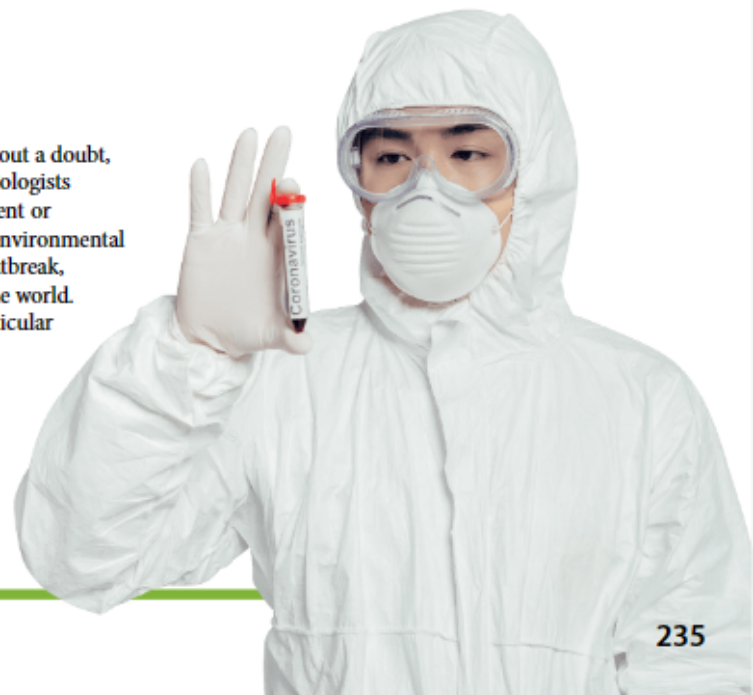
Cool Career

Epidemiologist

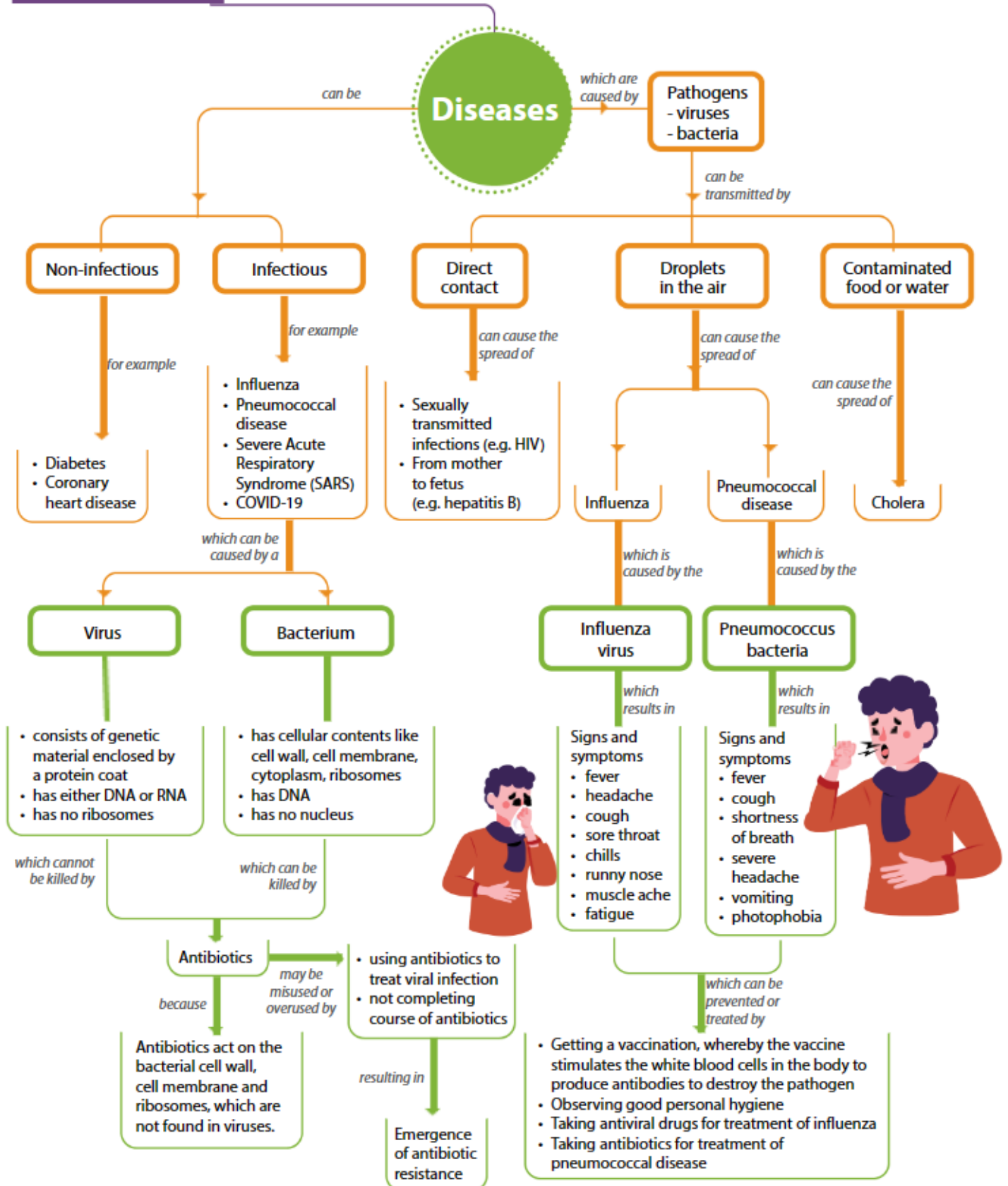
Have you seen movies about viral disease outbreaks? The scientist is, without a doubt, a crucial character in these movies. These scientists are known as epidemiologists (Figure 11.22). They help identify a disease, determine its cause, and prevent or minimise the spread of a disease. They work in a variety of areas such as environmental health, infectious diseases, chronic diseases and oral health. During an outbreak, epidemiologists are sent to various locations around the nation or even the world. They gather information and use statistical analysis to find out how a particular disease was introduced and spread.

Typically, an epidemiologist has an interest in research and investigation. He or she takes on novel challenges with an open and objective mindset. Their services in the public health sector also require epidemiologists to communicate effectively with other health professionals and the wider community.

Figure 11.22 Epidemiologist holding a potentially infectious blood sample



Let's Map It



Let's Review

Section A: Multiple-choice Questions

- 1 Which row correctly describes the difference between a bacterium and a virus?

	Feature	Bacterium	Virus
☐ A	cell membrane	absent	present
☐ B	protein coat	present	absent
☐ C	cytoplasm	absent	present
☐ D	ribosome	present	absent

- 2 Acquired Immune Deficiency Syndrome (AIDS) is a disease caused by the Human Immunodeficiency Virus (HIV). What are the similarities between AIDS and influenza?

- Both are caused by viruses.
- Both can be treated by antibiotics.
- Both can spread from one person to another.
- Both can be spread through contaminated food.

- ☐ A 1 and 3 only ☐ B 2 and 4 only
☐ C 1, 2 and 4 only ☐ D 1, 2, 3 and 4

- 3 Which of the following processes will **not** result in antibiotic-resistant bacteria?

- not completing dose of antibiotics
- vaccination
- taking antibiotics for viral diseases
- completing course of antibiotics as prescribed

- ☐ A 2 and 4 only ☐ B 1, 2 and 3 only
☐ C 2, 3 and 4 only ☐ D 1, 2, 3 and 4

- 4 Thomas has received a flu vaccination against a new type of flu. Which of the following is correct?

- ☐ A His body will not be able to fight against another infection from the same virus.
☐ B The flu vaccine contains a form of the virus that causes flu.
☐ C The flu vaccine works by killing the bacteria in his body.
☐ D The vaccine will make his white blood cells produce antibiotics.

Section B: Structured Questions

- 1 Figure 11.23 shows the structure of a virus.

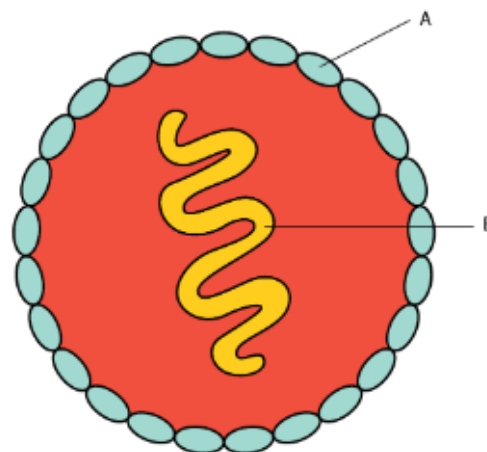


Figure 11.23

- (a) Identify structures A and B.
 (b) State **two** differences between a virus and a bacterium.

- 2 Fill in the blanks using appropriate words. The same word(s) may be used more than once.

A vaccine contains an agent that resembles the (a) _____. It prevents an (b) _____ by stimulating the (c) _____ to produce (d) _____ against the (e) _____. In the future, when the same (f) _____ enters the body, the white blood cells will recognise them and quickly produce large amounts of (g) _____ to destroy the pathogen before it has a chance to invade the body cells.

- 3 The bacteria *Streptococcus pneumoniae* causes the pneumococcal disease, which causes the alveoli in the lungs to swell up. Fluid and pus fill the alveoli, causing breathing difficulty.

- (a) Is *Streptococcus pneumoniae* a pathogen?
(b) Explain your answer in (a).

- 4 Mr Hassan went to see the doctor as he had a persistent cough, runny nose and greenish-yellow mucus. Without doing any tests, the doctor prescribed Mr Hassan a course of antibiotics for an infection. However, these signs could be a result caused by another type of infection that cannot be treated by antibiotics.

- (a) (i) Which other type of infection could Mr Hassan have?
(ii) Suggest **one** treatment that could be given for the infection stated in (a)(i).
(iii) Describe **three** ways in which Mr Hassan can reduce transmission of his infection to others.
(b) Mr Hassan has a habit of not taking the full course of his antibiotics. Instead, he stops his antibiotics once he feels better and keeps it for future use. Predict what could happen to the bacteria population if Mr Hassan continues to do this each time he has a bacterial infection.

- 5 Like humans, bacteria can also be infected by viruses. Bacteria can protect themselves against a viral infection. When a bacterium is infected by a virus, it makes RNA that specifically targets the virus. The RNA guides an enzyme to the virus' genetic material. The enzyme digests and destroys the virus' genetic material.

Given the above information, state the differences between how a bacterium and white blood cells in humans fight against a viral infection.

Section C: Free Response Questions

- 1 Most children receive vaccinations for infectious diseases such as measles, mumps and rubella. How do children who are vaccinated against an infectious disease help provide protection to those who are not vaccinated?
- 2 When COVID-19 struck the world in February 2020, many restaurants decided to install transparent separators on tables to separate their customers from one another. These separators have to be designed to prevent the spread of COVID-19 yet minimise inconvenience to users. They should be practical and sustainable.
- (a) How can separators prevent the spread of COVID-19?
(b) Name **two** properties that the materials used to make the separators should have.
(c) Based on what you already know about droplet infection, state **one** other detail that should be considered when designing the separator.



Link

Theory Workbook
Revision Worksheet 2

CHAPTER

12

Nutrition and Transport in Flowering Plants



What You Will Learn



- What are the structures of a leaf and their functions?
- What are the functions of xylem and phloem?
- What is photosynthesis?
- How can we study the movement of substances in plants?
- How does water enter a plant?
- How does water move up a plant?

We have learnt that plants respond to a light source by growing towards it. Do you know why this is so? How does light help a plant to grow?

Do you know that green plants are one of the few types of living things that can make their own food from the air we breathe? Find out all about these amazing feats of green plants in this chapter.

12.1 What Are the Leaf Structures and Their Functions?

Learning Outcomes

- Identify the cellular and tissue structure of a dicotyledonous leaf, as seen in transverse section using the light microscope and describe the significance of these features in terms of their functions, such as the distribution of chloroplasts for photosynthesis, stomata and mesophyll cells for gaseous exchange, and vascular bundles for transport.
- Describe how carbon dioxide reaches mesophyll cells in a leaf.

The leaf is sometimes referred to as one of the principal ‘factories’ of the world because it is where photosynthesis occurs. It is also the organ where other food substances such as fats and proteins are formed. These substances eventually become the food of all other living organisms, either directly or indirectly. As a ‘factory’, the leaf must be well equipped with the machinery for manufacturing food. How is the leaf adapted to its function of photosynthesis?

External Features of a Leaf

A typical green leaf consists of the leaf blade and the leaf stalk (Figure 12.1).

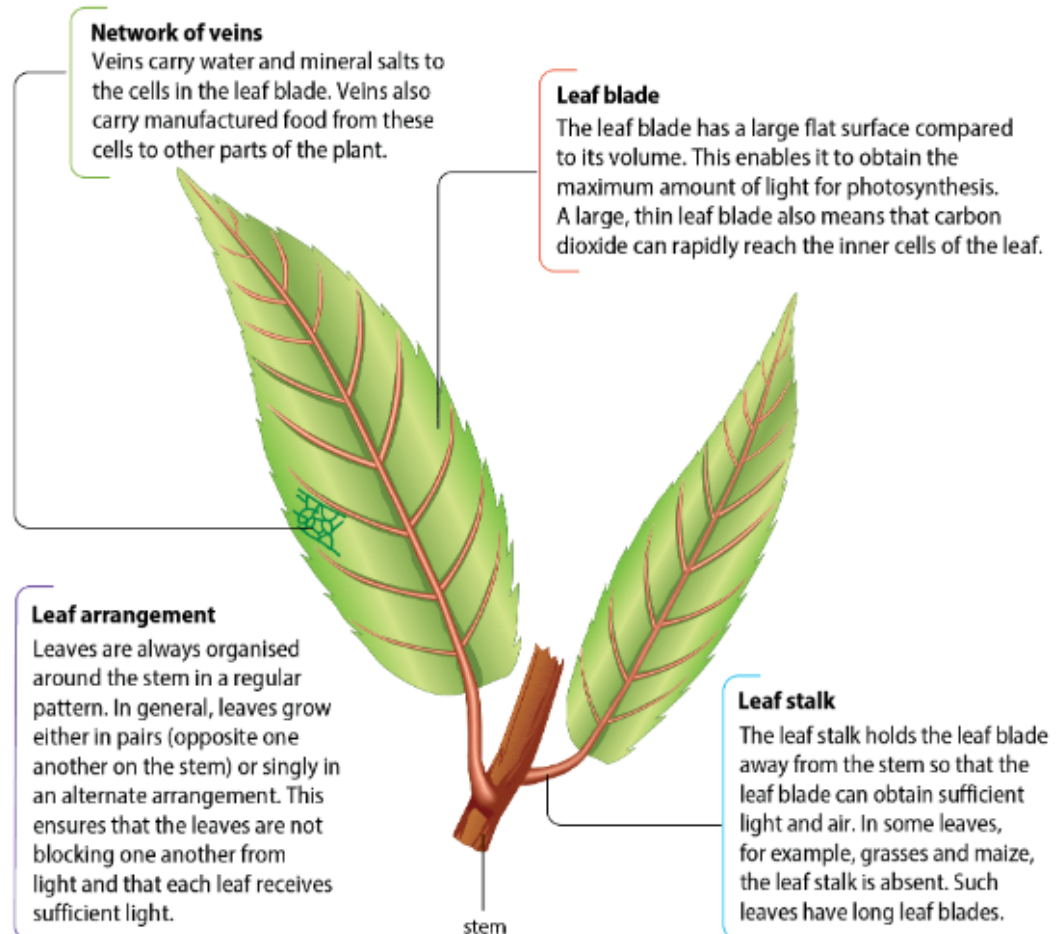


Figure 12.1 External features of a simple leaf



Internal Structure of the Leaf

Figure 12.2 shows the internal structures of a leaf.

Portion of the leaf blade as seen under the microscope

A leaf, cut transversely

veins

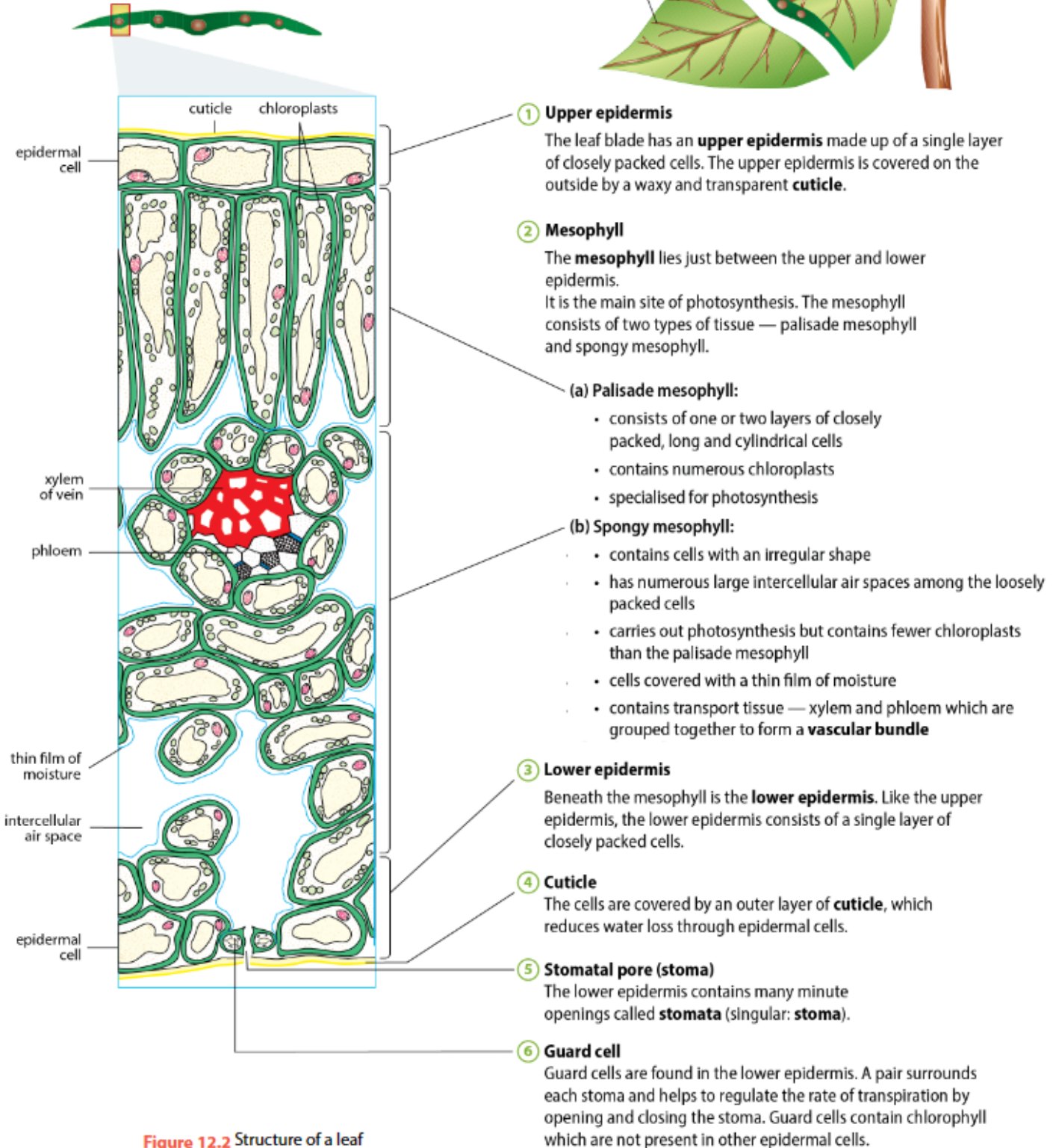


Figure 12.2 Structure of a leaf

How Is the Leaf Adapted for Photosynthesis?

The main features of the leaf and how these features are adapted for photosynthesis are summarised in Table 12.1.

Table 12.1 Adaptation of the leaf for photosynthesis

Adaptation	Function
Waxy cuticle on upper and lower epidermis	It reduces water loss through evaporation from the leaf. It is transparent for light to enter the leaf.
Stomata present in the epidermal layers	Stomata open in the presence of light, allowing carbon dioxide to diffuse in and oxygen to diffuse out of the leaf.
Chloroplasts containing chlorophyll in all mesophyll cells	Chlorophyll absorbs energy from light and transfers it to chemical stores of energy in glucose molecules.
More chloroplasts in upper palisade tissue	More light can be absorbed near the upper leaf surface.
Interconnecting system of air spaces in the spongy mesophyll (Figure 12.3)	The air spaces allow rapid diffusion of carbon dioxide and oxygen into and out of mesophyll cells.
Veins containing xylem and phloem situated close to mesophyll cells (Figure 12.4)	Xylem transports water and mineral salts to mesophyll cells. Phloem transports sucrose away from the leaf.



Disciplinary Idea

Structure and

Function

The structure of a plant is designed to ensure that plants obtain raw materials needed for them to photosynthesise.

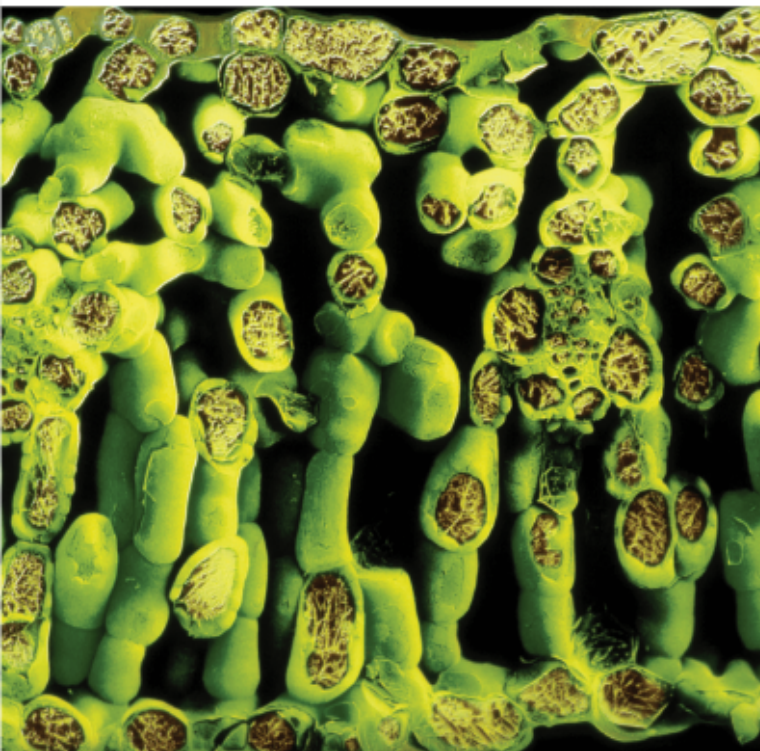


Figure 12.3 Colourised scanning electron micrograph of a section of a leaf (141x) showing intercellular air spaces

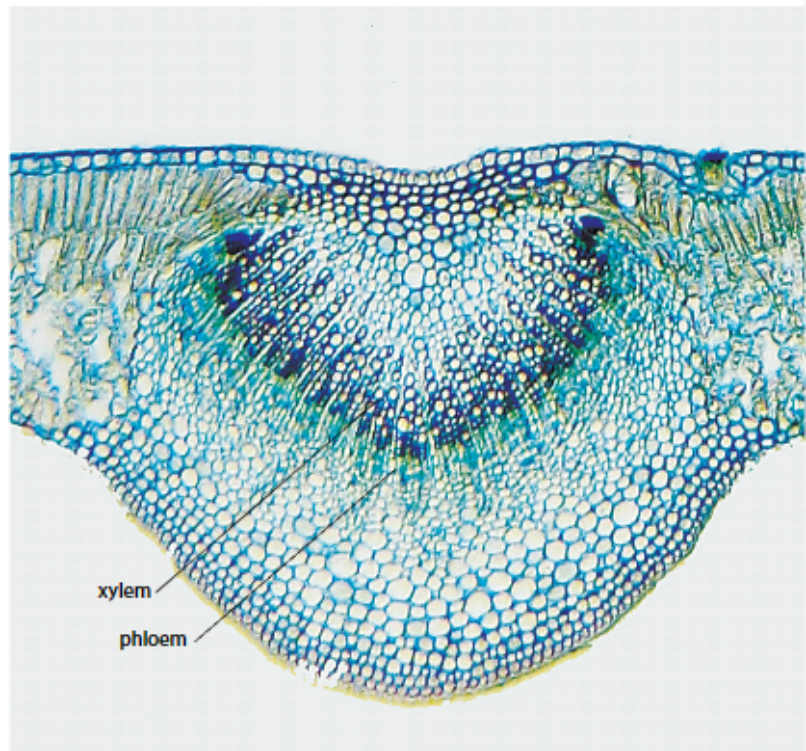


Figure 12.4 Light micrograph of a section of a leaf showing the locations of xylem and phloem

How Do Guard Cells Control the Size of Stomata?

Stomata generally open in the light and close in the dark.

Guard cells help to regulate the passage of gases between the leaf and the environment. For example, the guard cells can reduce the amount of water vapour escaping from the leaf. Stomata can close to reduce water loss even when a plant is in sunlight, such as on extremely hot days (Figure 12.5). In such situations, the excess loss of water causes the guard cells to become flaccid. Thus, the stomatal pore closes.

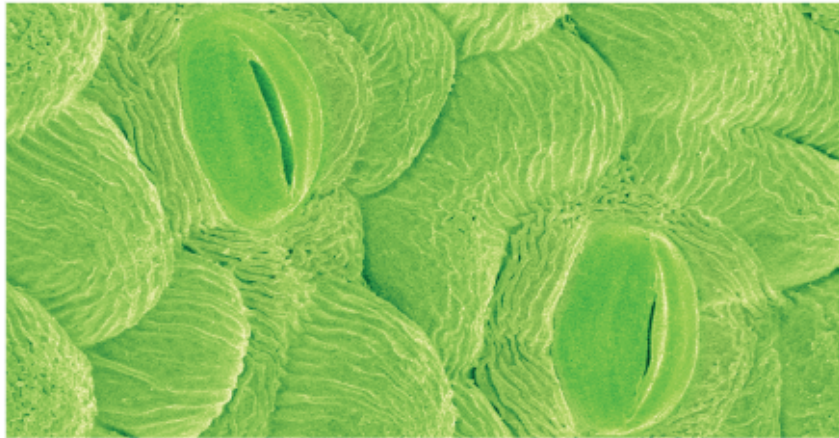


Figure 12.5 Stomata on a leaf viewed under 750x magnification

As the guard cells control the opening and closing of the stomata, they regulate the passage of gases such as carbon dioxide and oxygen into and out of the leaf (Figure 12.6).



Helpful Note

Stomata in the leaf are generally kept open during the day which allows carbon dioxide and oxygen to diffuse into and out of the leaf.



Helpful Note

Figure 12.6(a) shows the guard cells in sunlight.

- The guard cells manufacture glucose by photosynthesis. The increase in glucose concentration lowers the water potential of the cell sap in the cell.
- Water enters the guard cells by osmosis.
- They become turgid and more curved. This is because the cell wall around the stomatal pore (stoma) is thicker than the other parts of the cell. Hence, the cell curves around the stoma and the stoma opens.

Figure 12.6(b) shows the guard cells on a hot sunny day.

- When the leaf loses too much water in strong sunlight, the stomata close.
- Excess evaporation of water causes the guard cells to become flaccid, thus the stoma closes.
- This prevents excessive loss of water by the leaf.

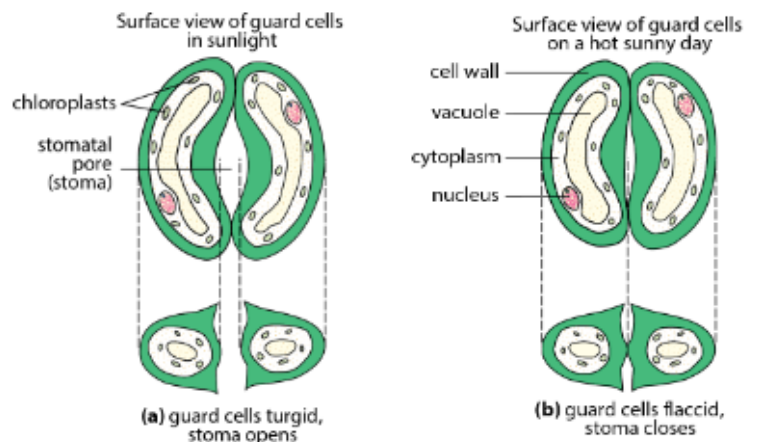


Figure 12.6 Opening and closing of a stoma

How Can We Demonstrate the Presence of Stomata in a Leaf?

Let's Investigate 12.1

Aim

To demonstrate the presence of stomata in a leaf

Procedure

- 1 Heat up a beaker of water to approximately 75 °C.
- 2 Pick up a fresh leaf with a pair of forceps and hold the leaf below the surface of the water (Figure 12.7). Observe carefully what happens on the surfaces of the leaf.
- 3 Record your observations.

Discussion

- 1 Explain what has taken place in the leaf as fully as you can.
- Hint** Air expands when heated.
- 2 Why must the water temperature be approximately 75 °C before taking readings?

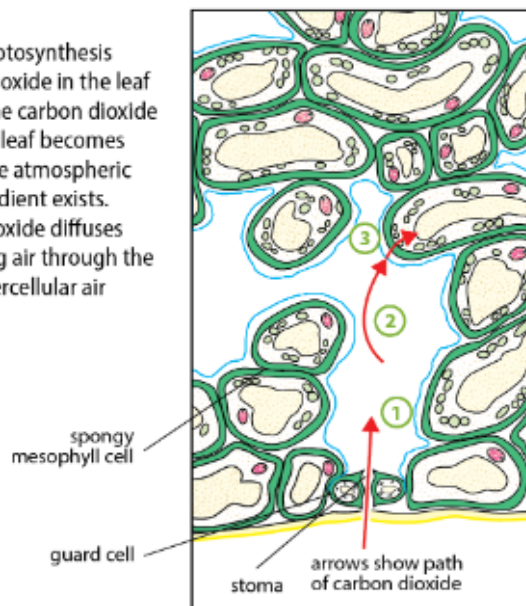


Figure 12.7 Experimental set-up to demonstrate the presence of stomata in a leaf

How Do Carbon Dioxide and Water Enter the Leaf?

Figure 12.8 shows how carbon dioxide enters the leaf through the stomata.

- 1 In daylight when photosynthesis occurs, the carbon dioxide in the leaf is rapidly used up. The carbon dioxide concentration in the leaf becomes lower than that in the atmospheric air, so a diffusion gradient exists. Therefore, carbon dioxide diffuses from the surrounding air through the stomata into the intercellular air spaces in the leaf.



- 2 The surfaces of the mesophyll cells are always covered by a thin film of water. This is so that carbon dioxide can dissolve in it.
- 3 The dissolved carbon dioxide then diffuses into the cells.

Figure 12.8 The path of carbon dioxide into the leaf

Figure 12.9 shows how xylem transports water and mineral salts to the leaf.

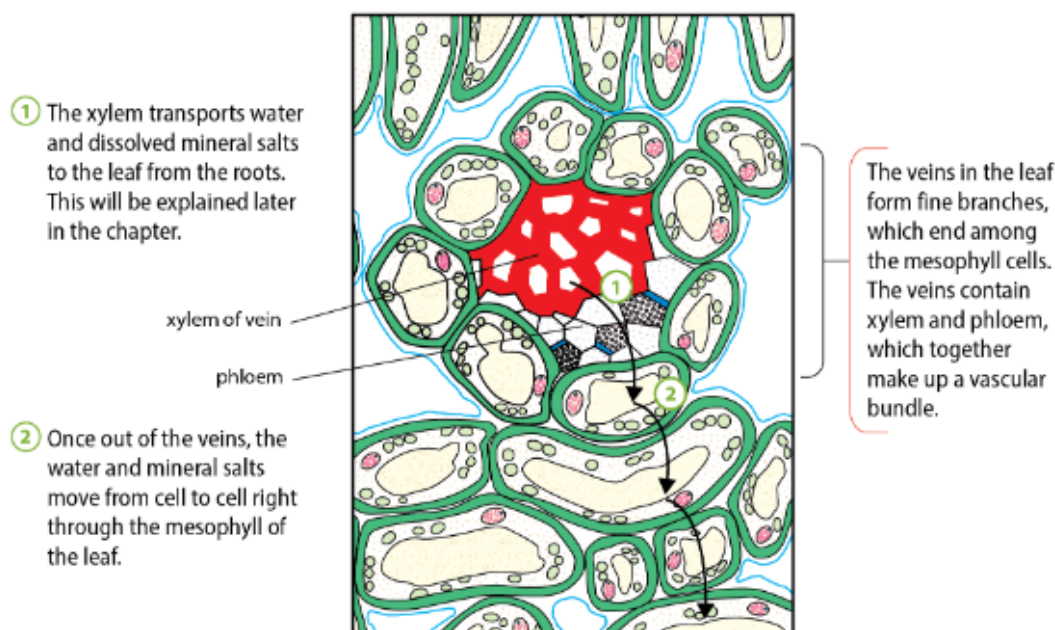


Figure 12.9 The path of water into the leaf

Once the green cells receive the essential raw materials such as carbon dioxide and water, they can manufacture food by photosynthesis. The phloem transports the sugars made in the leaf to other parts of the plant.

Let's Practise 12.1

- Water plants such as the water lily (Figure 12.10) have floating leaves, weak stems and roots that are embedded in the soil. The leaf is specially adapted for photosynthesis.

The leaf has the following features:

- stomata found only on the upper epidermis;
- thick cuticle covers the upper epidermis;
- no cuticle in the lower epidermis; and
- many large air chambers present near the lower surface of the leaf.

- The plant does not lack water. Suggest a reason for the thick cuticle covering the upper surface of the leaf.
- Suggest **two** functions of the large air chambers found near the lower surface of the leaf.

- Describe how atmospheric carbon dioxide enters a leaf and reaches the chloroplast of a mesophyll cell.



Water lilies

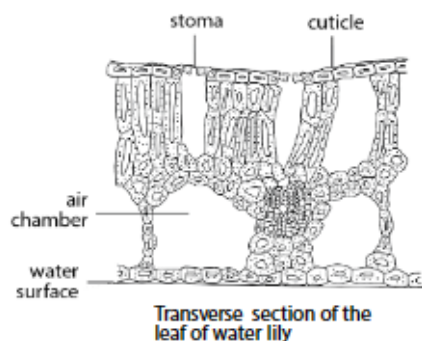


Figure 12.10



Link

Theory Workbook
Worksheet 12A

12.2 What Are the Functions of Xylem and Phloem?

Learning Outcome

- Identify the positions of and explain the functions of xylem vessels and phloem (sieve tube elements and companion cells) in sections of a herbaceous dicotyledonous leaf and stem, under the light microscope.



Helpful Note

Vascular tissues are a system of vessels that transport materials in plants.

If you have taken a tour in the nature reserve, you would have noticed that there are many tall trees. The tallest rainforest tree in Singapore is known as *Seraya*. It is about 60 m tall, equivalent to a 20-storey apartment block. Have you ever wondered how water and mineral salts or ions can be transported from the roots to the leaves at the top of the tree against gravity? What are the transport tissues in the tree? How are they suited for the transport of substances from one part of the tree to another?

Flowering plants have a system of vessels that run up and down the plants carrying materials. These vessels are called **transport** or **vascular tissues**. There are two types of transport tissues in plants: the **xylem** and the **phloem**.

Xylem tissue has two functions:

- conducting water and dissolved mineral salts from the roots to the stems and leaves
- providing mechanical support for the plant

The function of phloem tissue is to conduct manufactured food substances (sucrose and amino acids) from the green parts of the plant, especially the leaves, to other parts of the plant.

Xylem

How Is a Xylem Vessel Adapted for Its Function?

Xylem tissue consists mainly of xylem vessels (Figures 12.11). A **xylem vessel** is a long hollow tube stretching from the root to the leaf. The xylem vessel is a structure made up of many dead cells without cytoplasm or cross-walls (Figure 12.12). This reduces resistance to water flowing through the xylem.

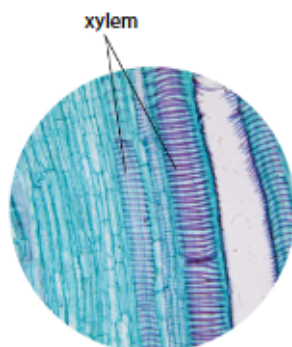


Figure 12.11 Photomicrograph showing xylem tissue in a dicotyledonous stem (L.S.) (two-dimensional view)

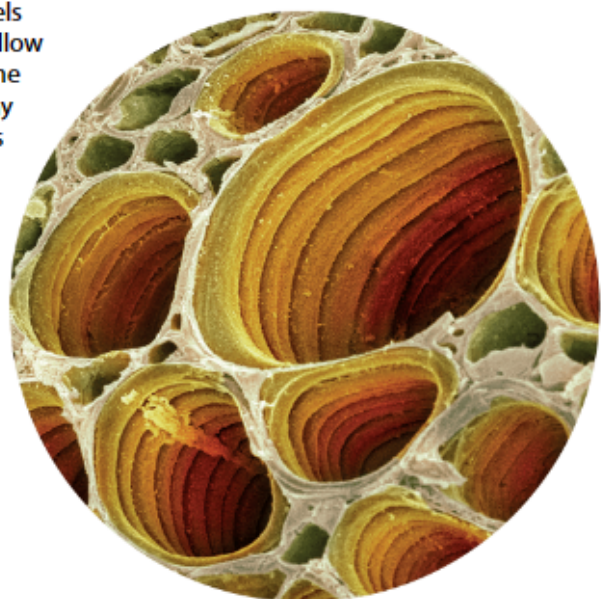


Figure 12.12 Hollow xylem vessels



The inner walls of xylem vessels are strengthened by deposits of a substance called **lignin**. Lignin may be deposited in the form of rings, spirals, or the whole vessel is lignified except in regions called pits (Figure 12.13). Together, all the xylem vessels provide mechanical support to the plant.

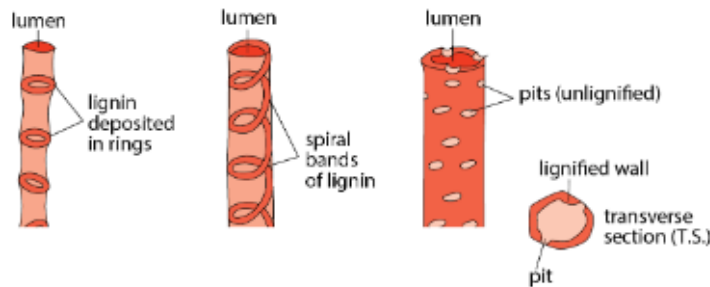


Figure 12.13 Xylem vessels showing the different patterns of lignification (three-dimensional view). Note how the whole wall of some vessels may be lignified except in regions called pits.

Phloem

How Is Phloem Adapted for Its Function?

Phloem consists mainly of **sieve tubes** and **companion cells** (Figures 12.14 and 12.15). Each sieve tube consists of a column of elongated, thin-walled living cells called **sieve tube cells** or **sieve tube elements**. The 'cross-walls' separating the cells have a lot of minute pores. These 'cross-walls' look like a sieve and so are called **sieve plates**.

A mature sieve tube cell has only a thin layer of cytoplasm inside the cell that is connected to cells above and below through the holes in the sieve plates. This allows the rapid flow of manufactured food substances through the sieve tubes.

Each sieve tube cell also has a companion cell beside it that provides nutrients and helps the sieve tube cell to transport manufactured food. The companion cell carries out the metabolic processes needed to keep the sieve tube cell alive. Each companion cell is a narrow thin-walled cell with many mitochondria, cytoplasm and a nucleus. The mitochondria provide the energy needed for the companion cells to load sugar from the mesophyll cells into the sieve tubes by active transport.

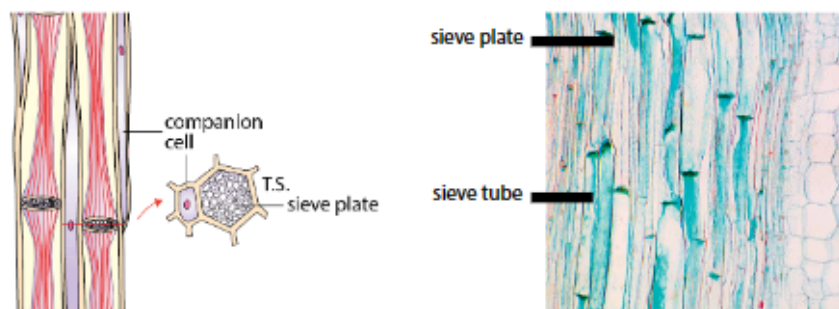


Figure 12.14 Some components of phloem tissue (three-dimensional view)

Figure 12.15 Photomicrograph showing phloem tissue in a dicotyledonous stem (L.S.) (two-dimensional view)

We shall now look at the distribution of vascular tissues in a stem and a root. The distribution of these tissues in a leaf has already been discussed in the previous section.

Vascular Tissues in Stems

Figures 12.16 to 12.18 show the organisation of vascular tissues in a dicotyledonous stem.

- ① Within a **vascular bundle**, the xylem is located closer inside. The phloem lies outside the xylem with a tissue called the **cambium** between them (Figure 12.17).
- ② The stem is covered by a layer of cells called the **epidermis**. The epidermal cells are protected by a waxy, waterproof cuticle that greatly reduces evaporation of water from the stem.

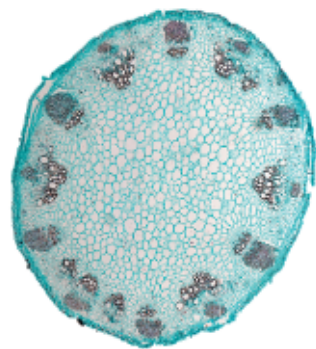


Figure 12.16 Photomicrograph showing the transverse section of a young stem

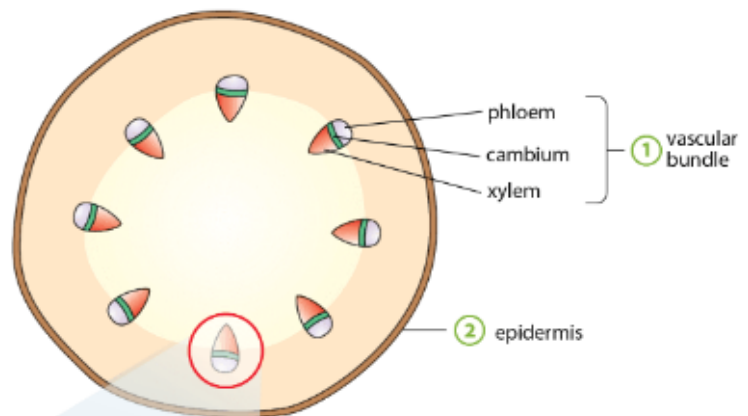


Figure 12.17 Generalised young dicotyledonous stem (T.S.)

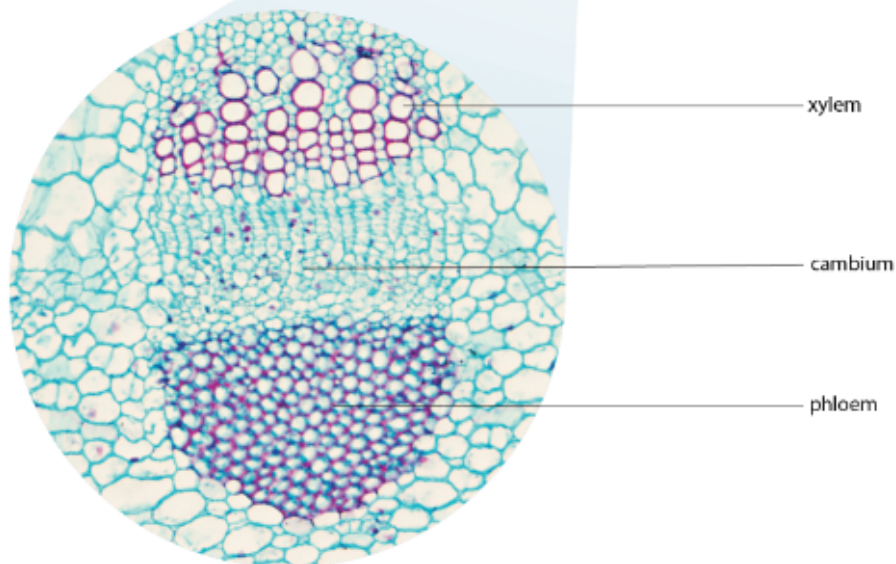


Figure 12.18 Photomicrograph showing a vascular bundle (35x)



Link

Practical Workbook
Experiment 12A

Vascular Tissues in Leaves

Figure 12.19 shows the arrangement of the vascular bundles in a leaf. Vascular bundles are found along the spongy mesophyll. Within a vascular bundle, the xylem is closer to the upper surface of the leaf and phloem closer to the lower surface of the leaf.



Figure 12.19
Arrangement of vascular bundles in a leaf

Vascular Tissues in Roots

Figures 12.20 and 12.21 show the vascular tissues in a dicotyledonous root.

- ① The epidermis of the root is the outermost layer of cells. It bears root hairs.
- ② Each root hair is a long and narrow extension growing out of an epidermal cell (see Figure 12.51 on page 268). *The long and narrow extension of the root hair increases the surface area-to-volume ratio of the root hair cell. The rate of absorption of water and mineral salts is increased through this adaptation.*

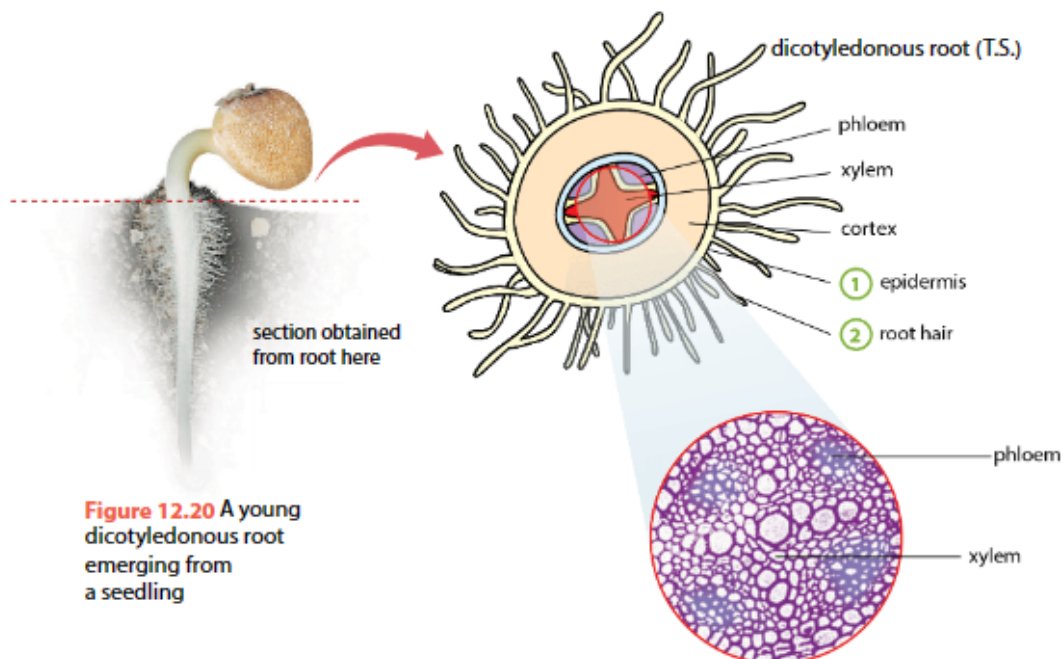


Figure 12.20 A young dicotyledonous root emerging from a seedling

Figure 12.21
Photomicrograph showing the transverse section of a young root

Let's Practise 12.2

- 1 Figure 12.22 shows a section of a stem. Which tissue
 - (a) transports water up the stem?
 - (b) transports sugars and amino acids?
 - (c) provides support for the stem?

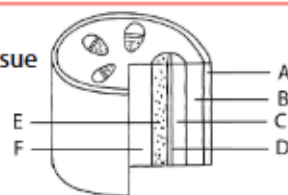


Figure 12.22



Link

Theory Workbook
Worksheet 12B

12.3 What Is Photosynthesis?

Learning Outcomes

- State that chlorophyll absorbs light energy and converts it into chemical energy for the formation of carbohydrates and their subsequent uses.
- Briefly explain why most forms of life are completely dependent on photosynthesis.
- State the equation, in words and symbols, for photosynthesis.
- Investigate and discuss the effects of varying light intensity, carbon dioxide concentration and temperature on the rate of photosynthesis.
- Discuss light intensity, carbon dioxide concentration and temperature as limiting factors on the rate of photosynthesis.

Humans and other animals need to eat to survive. However, have you ever seen a plant eating? Aside from some carnivorous plants that trap and digest insects, most plants do not 'eat' in the sense that animals do. Do plants get hungry? How do they fulfil their nutritional requirements?

In order to perform the various vital functions of the body, a living organism must be provided with sufficient energy. This energy is obtained from breaking down energy-rich organic molecules in food. *If we trace the origin of the organic molecules in food, we will always find that they come from green plants.*

Imagine that you had coffee, toast and a hard-boiled egg for breakfast (Figure 12.23). Where did the organic molecules in each of these foods come from?

If you trace these organic molecules back to their origin, you will realise that they come, directly or indirectly, from plants.

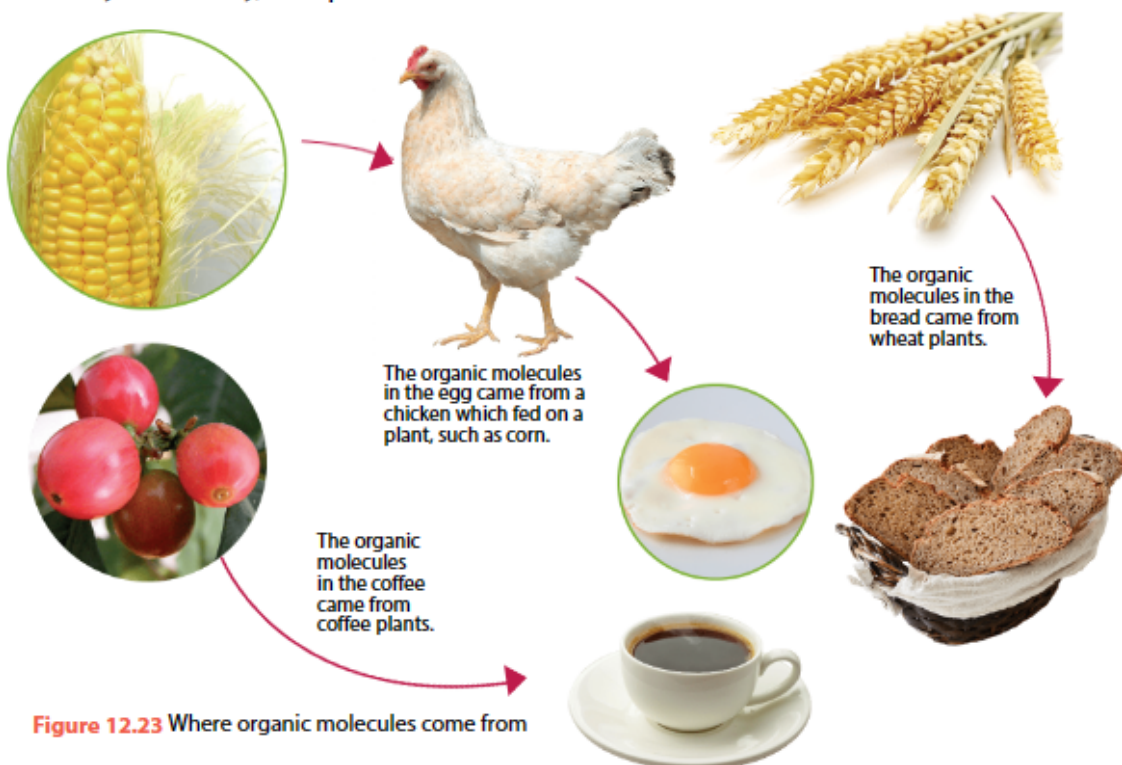


Figure 12.23 Where organic molecules come from



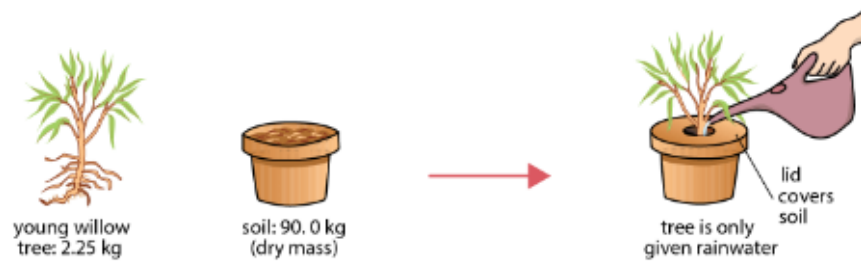
Link

How is energy transferred between organisms? Read more about it in Chapter 13.

Where Do Plants Get Their Food?

In 1649, the Dutch physician Jan-Baptista van Helmont carried out an ingenious experiment to test the idea that plants get their food from the soil. The details of his experiment are shown in Figure 12.24.

- 1 A young willow tree was planted in soil and given only rainwater.



- 2 Five years later, the tree was weighed.

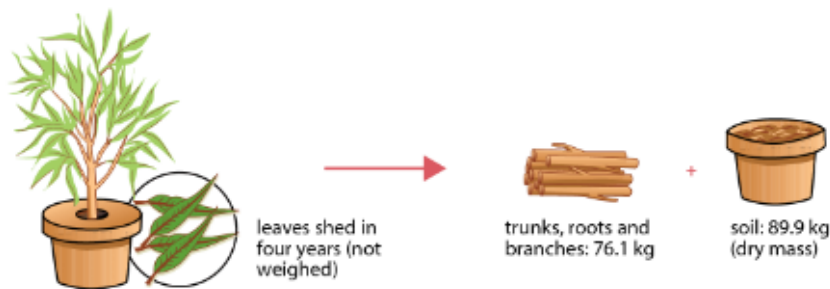


Figure 12.24 Jan-Baptista van Helmont's willow experiment

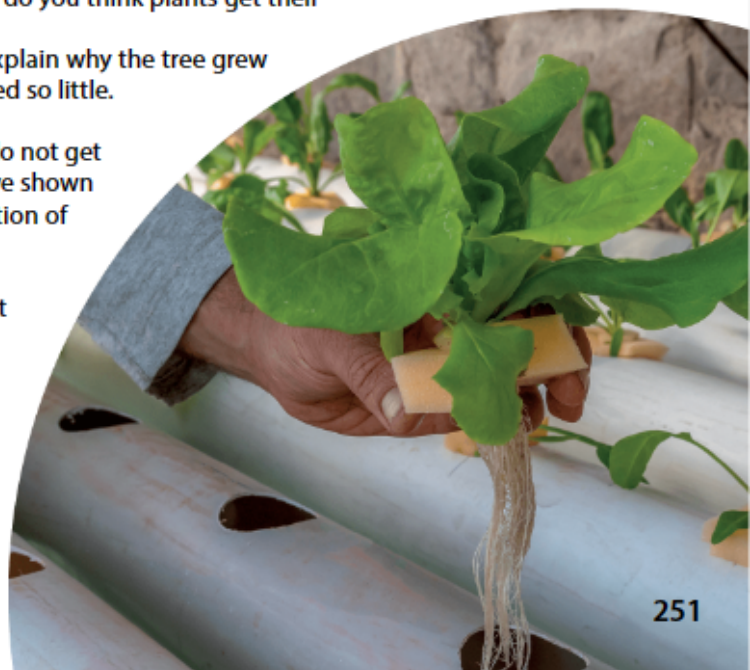
Look carefully at the figures given for the masses.

- By how much did the mass of the willow tree increase over the five years of the experiment?
- By how much did the mass of the soil decrease?
- Looking at the results of this experiment, do you think plants get their food from the soil?
- Suggest another hypothesis that could explain why the tree grew so much but the mass of the soil decreased so little.

Helmont's experiment proved that plants do not get their food from soil. Other experiments have shown that plants can grow well in a soil-free solution of mineral salts (Figure 12.25).

Soil contains water and mineral salts but not carbon compounds. Yet carbohydrates like glucose, which contain carbon and store energy, are found abundantly in plants. If not from the soil, where do the carbon and energy in glucose come from?

Figure 12.25 Plants can grow even when their roots are not planted in soil.





Where Could Plants Obtain Carbon and Energy From?

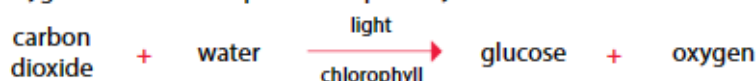
We know that air contains carbon dioxide. Could air be the source of carbon for green plants? Green plants are exposed to light. Could light be the source of energy for green plants?

If carbon dioxide and light are the sources of carbon and energy for making organic molecules in plants:

- How is carbon dioxide in the air converted into large molecules such as carbohydrates?
- How is the energy in light transformed into the chemical energy stored in these organic molecules?

The answer lies in an amazing process called *photosynthesis* (Greek: *photo* = light; *synthesis* = process of putting together or manufacturing). Practically all life on Earth ultimately depends on photosynthesis.

In photosynthesis, chlorophyll (the green pigment in plants) absorbs the energy from light to make glucose from carbon dioxide and water. This process releases oxygen. The overall equation for photosynthesis is shown below:



How Can We Study Photosynthesis?

To find out what happens in photosynthesis, you have to design experiments to test your ideas, just like van Helmont did. However, you need to first have the basic knowledge given in Table 12.2.

Table 12.2 Basic knowledge required to carry out experiments on photosynthesis

Basic Knowledge	Explanation	Action to Take
Glucose is first formed from carbon dioxide during photosynthesis.	• The simplest energy-rich organic molecules are carbohydrates. • The simplest stable form of carbohydrates is glucose.	Not applicable.
Presence of starch in the leaves suggests that photosynthesis has taken place.	• When glucose is formed more quickly than it is used up, the excess glucose is converted to starch for storage. • Note, however, that starch formation does not indicate that photosynthesis has taken place. Starch can be formed even in the roots or underground storage organs of plants.	Test for starch using iodine solution (see Let's Investigate 12.2).
Destarching (removal of starch) must be carried out on the plants before the experiments.	• This ensures that starch is absent in the leaves prior to the experiments. • Thus, all starch present in the leaves after the experiments must have been formed during the experiments.	• Put the plants in the dark for two days. • In darkness, photosynthesis stops and enzymes in the leaves convert starch to sucrose, which is transported to other parts of the plant (see page 262).



Link

Carbohydrates are organic molecules made up of carbon, hydrogen and oxygen. Recall what you learnt about biological molecules in Chapter 3.



Link

Iodine turns blue-black in the presence of starch. Recall what you learnt in Chapter 3.

How Can We Show That Photosynthesis Has Taken Place?

You can show that photosynthesis has taken place by testing for the presence of starch in leaves. The equation for photosynthesis shows us that glucose is the carbohydrate that is produced. Yet in experiments on photosynthesis, we often test for starch to show that photosynthesis has taken place. This is because glucose is always present in all leaves. However, excess glucose produced during photosynthesis is converted to starch and stored in the leaves. Hence, if starch is absent at the beginning of the experiment but present at the end of the experiment, it shows that photosynthesis has taken place.

Let's Investigate 12.2

Aim

To test for the presence of starch in a leaf

Procedure

- 1 Remove a green leaf from a plant that has been exposed to light for a few hours.
- 2 Immediately put the leaf in boiling water for two minutes to denature the enzymes in the leaf and stop chemical reactions in the leaf.
- 3 Put the boiled leaf in a boiling tube containing some alcohol or ethanol to decolourise the leaf. Place the boiling tube in a beaker of hot water (Figure 12.26). The leaf has to be decolourised so that the colour of the iodine can be clearly observed. The alcohol will remove the green pigment chlorophyll from the leaf. The leaf will become colourless/white.
- 4 The leaf is now very brittle. Gently remove the leaf and put it back into the hot water. This softens the leaf and makes it more permeable to iodine solution.
- 5 Remove the leaf and spread it evenly on a white tile. Add a few drops of iodine solution to the leaf.

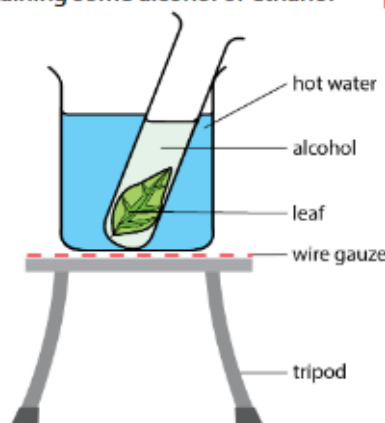


Figure 12.26 Boiling tube in a beaker of hot water

CAUTION!
Never heat the tube of alcohol directly with a Bunsen flame. Turn off the Bunsen flame before putting the tube in hot water. Alcohol is highly flammable.

Observation

- 1 What is the colour of the alcohol
 - (a) before the leaf is put in?
 - (b) ten minutes after the leaf is put in?
- 2 What is the colour of the leaf after ten minutes?
- 3 Explain your observation after adding a few drops of iodine solution to the leaf.

Discussion

- 1 How does the alcohol change the leaf?
- 2 What is the purpose of putting the leaf in boiling water in step 2?



Link

Practical Workbook
Experiment 12B

Now that you are able to test whether photosynthesis has taken place, you can test whether plants use light and carbon dioxide in photosynthesis.

Do Plants Use Light in Photosynthesis?

Let's Investigate 12.3

Aim

To find out whether light is necessary for photosynthesis

Procedure

- 1 Destarch a potted plant by placing it in the dark for two days.
- 2 Remove one leaf. Test it for starch as described in Let's Investigate 12.2.
- 3 Place a leaf, which is still attached to the plant, between two pieces of black paper (Figure 12.27). Each piece of paper has a certain pattern cut out from it. Fasten the pieces of paper using paper clips. Place the plant in strong light.
- 4 After a few hours, remove the leaf, decolourise it and test it for starch.
- 5 Make a drawing of the leaf to show the regions that are stained blue-black.

Conclusion and Discussion

- 1 What conclusion can you draw from this investigation?
- 2 Why must you test a leaf for starch before carrying out this experiment?

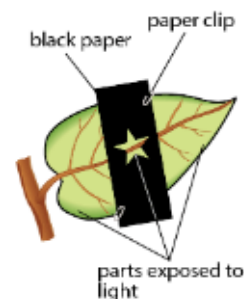


Figure 12.27 Place a leaf between two pieces of black paper.



Helpful Note

Vibrant variegations
Most **variegated** leaves have white or yellow patches, but some have more intense colours like pink, red or purple (Figure 12.29).



Figure 12.29 Plants with leaves that are not completely green

You now know that light is necessary for photosynthesis. However, how do plants capture light?

How Do Plants Absorb Light?

Chlorophyll is a pigment in plants that absorbs light. The green colour in leaves is due to the presence of chlorophyll.

Let's Investigate 12.4

Aim

To find out whether chlorophyll is necessary for photosynthesis

Procedure

- 1 Destarch a plant with variegated leaves, such as *Duranta*, by placing it in the dark for two days.
- 2 Expose the plant to strong light for a few hours.
- 3 Remove one leaf. Make a drawing to show the distribution of the green parts, which are the parts that contain chlorophyll (Figure 12.28).
- 4 Decolourise the leaf and test it for starch.
- 5 Make a drawing of the leaf to show the distribution of the blue-black colour. Compare this with your drawing in step 3.

Discussion

Suggest an explanation for your observation.

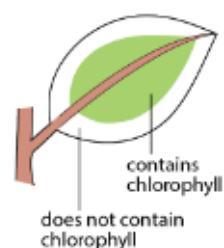


Figure 12.28 In a **variegated** leaf, with green and white parts, only the green parts contain chlorophyll.



Word Alert

Variegated: with streaks and patches of different colours



Link

Practical Workbook
Experiment 12C



Do Plants Use Carbon Dioxide in Photosynthesis?

Let's Investigate 12.5

Aim

To find out whether carbon dioxide is necessary for photosynthesis

Procedure

- 1 Destarch two potted plants by placing them in the dark for two days.
- 2 Enclose the pots in polythene bags. Secure the bags to the plant stems.
- 3 Place one pot in the bell jar as shown in Figure 12.30. The plant does not have a supply of carbon dioxide from the air because soda lime and potassium hydroxide solution rapidly absorb carbon dioxide.
- 4 Set up a control using pebbles and water in place of soda lime and potassium hydroxide solution respectively.
- 5 Leave both set-ups in strong light for a few hours.
- 6 Remove a leaf from each plant. Test the leaves for starch.

Observation

What do you observe from the test on the two leaves?

Conclusion

State a conclusion from this investigation.

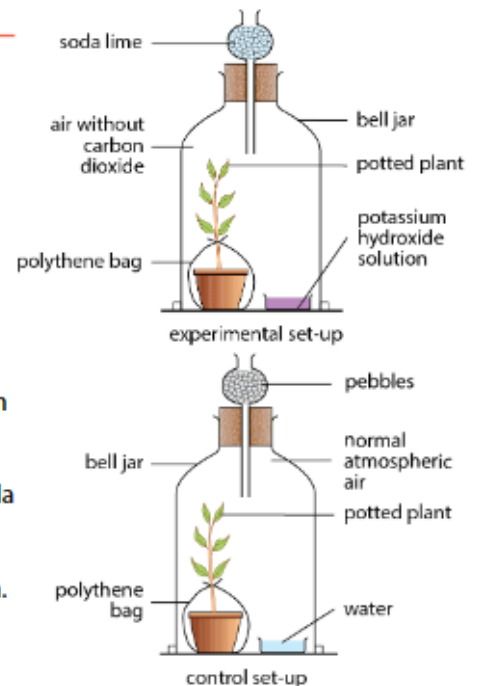


Figure 12.30 Experimental set-up to find out whether carbon dioxide is necessary for photosynthesis

What Gas Is Given Off During Photosynthesis?

During photosynthesis, plants take in carbon dioxide and give off another gas. How can you find out what gas this is?

Let's Investigate 12.6

Aim

To find out what gas is given off during photosynthesis

Procedure

- 1 Set up some freshwater plants, such as *Hydrilla* or *Elodea*, as shown in Figure 12.31. (Refer to Experiment 12D in the Practical Workbook for details on how to set up the experiment and the control.)
- 2 Dissolve 2–10 g of sodium hydrogencarbonate in the water in the beaker. This provides dissolved carbon dioxide to the plant.
- 3 Place the set-up in strong light for a few hours.
- 4 You will notice that gas bubbles form on the leaves in the beaker placed in light. These bubbles will rise up the test-tube and displace the water downwards. When the tube is about half-filled with the gas, remove the tube by placing a thumb over its mouth.
- 5 Test the gas with a glowing splint. Light a small splint, let it burn for a few seconds then blow out the flame. While the ember at the tip is still glowing, place it into the gas sample. If the glowing splint reignites, the gas is oxygen.
- 6 Record your observation.

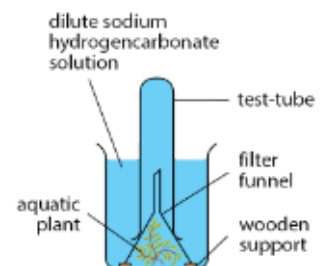


Figure 12.31 Experimental set-up to find out what gas is given off during photosynthesis



Link

Practical Workbook
Experiment 12D

Observation

- 1 What gas is given off by the water plants exposed to light?
- 2 What happens in the control set-up?

Discussion

- 1 Why is it important that no air is trapped in the test-tube at the beginning of the experiment?
- 2 What does the rate of gas production indicate?

You have learnt about carbohydrates in Chapter 3. A simple carbohydrate, such as glucose, has the chemical formula $C_6H_{12}O_6$, while carbon dioxide has the chemical formula CO_2 .

- How many carbon atoms does one molecule of glucose contain? How many molecules of carbon dioxide will be needed to make one molecule of glucose in terms of the number of carbon atoms?
- What chemical element does a carbohydrate molecule contain that is not found in carbon dioxide? Suggest where a plant may obtain this element.

Hint Look carefully at the word *carbohydrate*.

What Conditions Are Essential for Photosynthesis?

Let's Investigate 12.3 to 12.5 demonstrate the need for light, carbon dioxide and chlorophyll before starch can be produced in leaves.

Light, carbon dioxide and chlorophyll are thus essential for photosynthesis.

For photosynthesis to take place, a suitable temperature and sufficient water are also needed.

Photosynthesis depends on enzyme reactions in the chloroplasts. The effect of temperature on enzyme activity has already been discussed in Chapter 4. Therefore, a *suitable* temperature is required for photosynthesis to take place.

So far you have learnt what is essential for photosynthesis to occur. You have also learnt that oxygen is given off during photosynthesis.

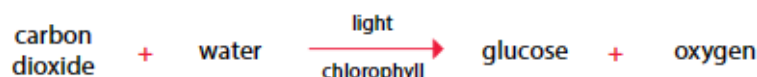
What Happens During Photosynthesis?

Photosynthesis is the process by which plants synthesise carbohydrates (e.g. glucose) from water and carbon dioxide. Water and carbon dioxide are the raw materials for photosynthesis. Oxygen is released during the process.

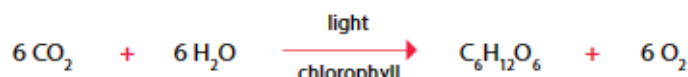
During photosynthesis, chlorophyll absorbs energy from light and transfers it to chemical stores of energy in carbohydrates (e.g. glucose), which are synthesised from water and carbon dioxide. Oxygen is released as a by-product.



The overall process of photosynthesis can be summarised using this word equation:



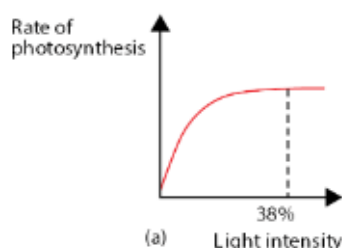
We can also write a balanced chemical equation for photosynthesis like this:



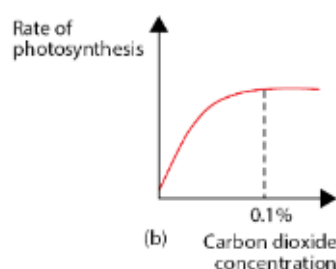
The actual process is much more complicated than the above equation. Many steps are involved before glucose is formed.

The rate of photosynthesis is affected by external factors such as light intensity, concentration of carbon dioxide and temperature.

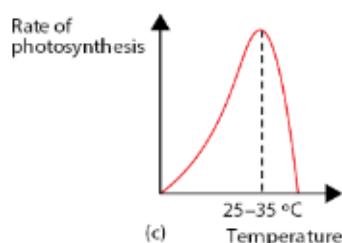
Let's Investigate 12.7 to 12.9 study the effect of the three factors on photosynthesis. Figure 12.32 shows the effect of the three factors on the rate of photosynthesis.



Without enough light, a plant cannot photosynthesise very fast, even if there is plenty of water and carbon dioxide. Increasing the light intensity increases the rate of photosynthesis, until a constant rate is reached. When more light is supplied to the plant, the amount of energy for photosynthesis increases and this increases the rate of photosynthesis.



Even if there is plenty of light, a plant cannot photosynthesise if it has insufficient carbon dioxide. Increasing the carbon dioxide concentration increases the rate of photosynthesis, until a constant rate is reached. When there is more carbon dioxide available to the plant, it can produce more glucose.



Increasing the temperature to the optimum temperature increases the rate of photosynthesis. Increasing temperature beyond the optimum decreases the rate of photosynthesis because of enzyme denaturation.

Figure 12.32 How the three factors affect the rate of photosynthesis



Word Alert

Intensity: the strength of something that can be measured



Link

The rate of enzyme reaction is affected by temperature. Increasing the temperature above the optimum causes a decrease in the rate of enzyme reaction. Recall what you learnt in Chapter 4.

What is the effect of varying light intensity on the rate of photosynthesis?

Let's Investigate 12.7

Aim

To investigate the effect of different light intensities on the rate of photosynthesis
(This experiment assumes that the rate of oxygen produced is directly proportional to the rate of photosynthesis.)

Procedure

- 1 Set up the apparatus as shown in Figure 12.33 with the cut end of the water plant positioned upwards. (Refer to Experiment 12E in the Practical Workbook for details.)

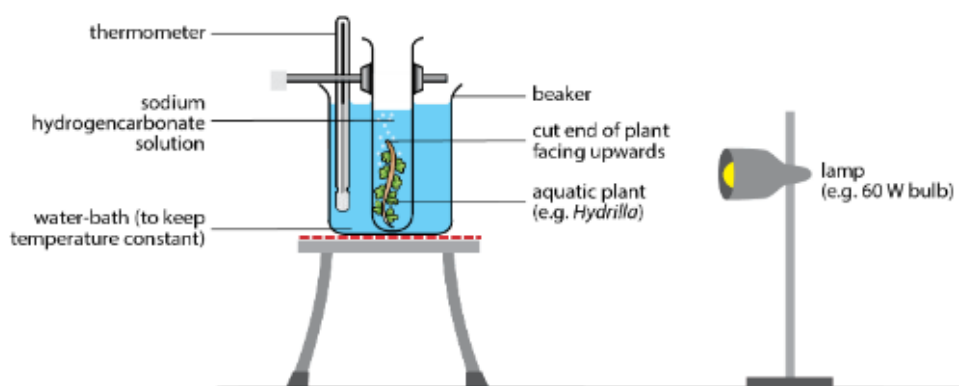


Figure 12.33 Experimental set-up to investigate the effect of different light intensities on the rate of photosynthesis

- 2 Bubbles are given off from the cut end of the plant. Allow some time for the plant to adapt to the conditions provided before taking readings.
- 3 When the bubbles are produced at a regular rate, count the number of bubbles over a period of five minutes. Repeat this a few times to obtain the average rate.
- 4 Repeat step 3 with the light source closer to the plant, e.g. 80 cm, 40 cm, 30 cm, 20 cm, 15 cm and 10 cm. Note that the nearer the light source is to the beaker, the higher the light intensity that the plant is exposed to.
- 5 Record your results in a table. Plot a graph to show the rate of bubbling per minute against the distance between the lamp and the plant.

Conclusion

From your investigation, what is the effect of light intensity on photosynthesis?
(This is based on the assumption that the higher the rate of air bubbles given off, the higher the rate of photosynthesis.)

Discussion

- 1 Why is sodium hydrogencarbonate solution used instead of water?
- 2 What conditions are you allowing for in step 2? Why do you wait for some time before taking the readings?
- 3 State a source of error.



Link

Practical Workbook
Experiment 12E

What is the effect of varying temperature on the rate of photosynthesis?**Let's Investigate 12.8****Aim**

To investigate the effect of different temperatures on the rate of photosynthesis

Procedure

- 1 Carry out step 1 from Let's Investigate 12.7.
- 2 Place a lamp (e.g. 60 W bulb) 10 cm away from the plant. Keep this distance constant throughout the investigation.
- 3 Add ice-cold water to the water bath to keep the temperature at 5 °C. Allow some time for the plant to adapt to the conditions provided before taking the readings.
- 4 Count the number of bubbles over a period of five minutes. Repeat this a few times to obtain an average rate.
- 5 Repeat step 4 at different temperatures, e.g. 15 °C, 25 °C, 35 °C, 45 °C, 55 °C, 65 °C and 75 °C. For each temperature, new sodium hydrogencarbonate solution should be used.
- 6 Record your results in a table. Plot a graph to show the rate of bubbling per minute against the temperature.

Conclusion

- 1 From your investigation, what is the effect of increasing the temperature from 5 °C to 35 °C?
- 2 At what temperature is the rate of bubbles given off the highest? This is the optimum temperature.

Discussion

What happens when the temperature is increased beyond the optimum temperature? Explain your answer.



Link

Practical Workbook
Experiment 12F

What is the effect of varying carbon dioxide concentration on the rate of photosynthesis?**Let's Investigate 12.9****Aim**

To investigate the effect of different carbon dioxide concentrations on the rate of photosynthesis

Procedure

- 1 Carry out step 1 from Let's Investigate 12.7.
- 2 Place a lamp (e.g. 60 W bulb) 10 cm away from the plant. Keep this distance constant throughout the investigation.
- 3 Conduct the investigation at room temperature.
- 4 Use different concentrations of sodium hydrogencarbonate solutions, e.g. 0.01 mol dm⁻³, 0.02 mol dm⁻³, 0.03 mol dm⁻³, 0.04 mol dm⁻³, 0.05 mol dm⁻³, 0.06 mol dm⁻³, up to 0.1 mol dm⁻³. (These are proportional to the carbon dioxide concentrations in the solution.)
- 5 When the bubbles are coming out at a regular rate, measure the rate of bubbles per minute for each concentration of the sodium hydrogencarbonate solution.
- 6 Record your results in a table. Plot a graph to show the number of bubbles per minute against the concentration of the solution.

Discussion

How do the concentrations of sodium hydrogencarbonate solutions affect the rate of photosynthesis?

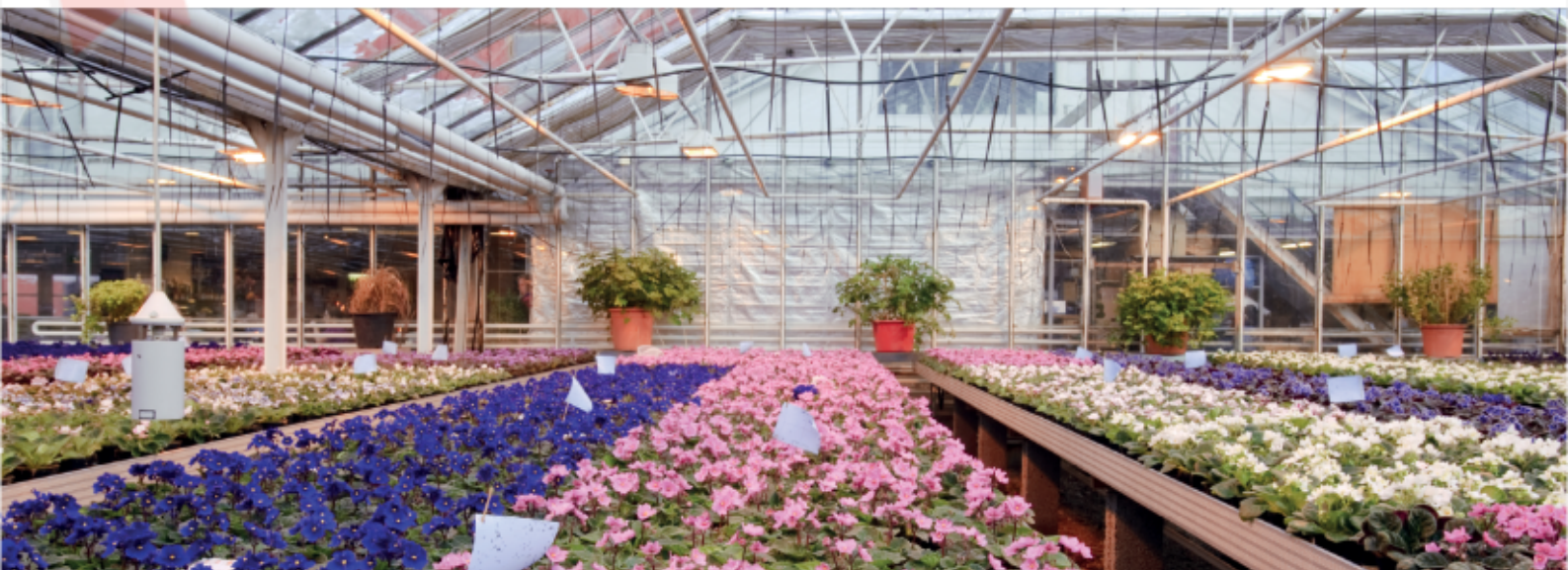


Figure 12.34 In commercial greenhouses, the temperature can be controlled, and more carbon dioxide can be added to the air to make plants grow better. Plants also get plenty of light!



Tech Connect

Green plants have the ability to convert solar energy into stored chemical energy. This has inspired many scientists and engineers to design devices that can harness energy from thin air (Figure 12.35). This method of 'artificial photosynthesis' is still in its early phases of development. It signals the approach of a new type of technology that is environmentally friendly.

The solar fuel generator is a small device that converts light, carbon dioxide and water into oxygen and formic acid. Formic acid is able to release a considerable amount of energy and can be used as a fuel to power an engine. In this way, the device operates like an artificial leaf, converting light energy from the sun to chemical energy.

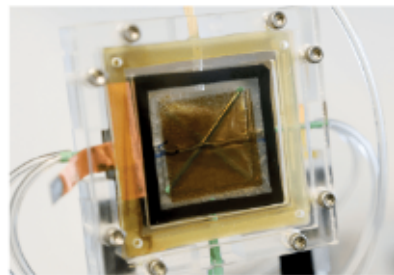


Figure 12.35 Early prototype solar fuel generator

What Are the Limiting Factors in Photosynthesis?

Study Figure 12.36. Initially, as the light intensity increases, the rate of photosynthesis increases from 0 to A. Here, *light intensity is the limiting factor*. A **limiting factor** is any factor that directly affects the rate of a chemical reaction. The rate of the reaction can be increased only if the value of the limiting factor is increased.

Beyond point A, light is no longer the limiting factor since the rate of photosynthesis remains constant even though the light intensity increases. Some other factor, possibly temperature or carbon dioxide concentration, becomes the limiting factor that causes the levelling off of the graph along AB.

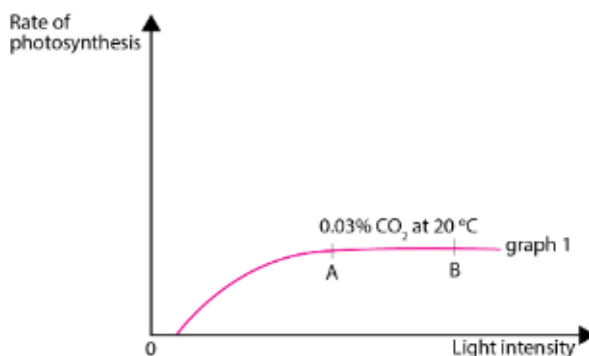


Figure 12.36 Effect of increasing light intensity on the rate of photosynthesis at 0.03% CO_2 at 20 °C



Link

Chemistry

We learn that rates of reactions are affected by concentration, pressure, particle size and temperature.

Now look at Figure 12.37. When the temperature remains constant and the carbon dioxide concentration of the environment is raised to 0.13%, the rate of photosynthesis greatly increases as shown in graph 2. This indicates that *carbon dioxide concentration is the limiting factor* in AB in graph 1.

Under natural conditions, carbon dioxide is an important limiting factor since atmospheric carbon dioxide remains constant at about 0.03%. Its concentration can be raised well above 0.03% only under experimental conditions.

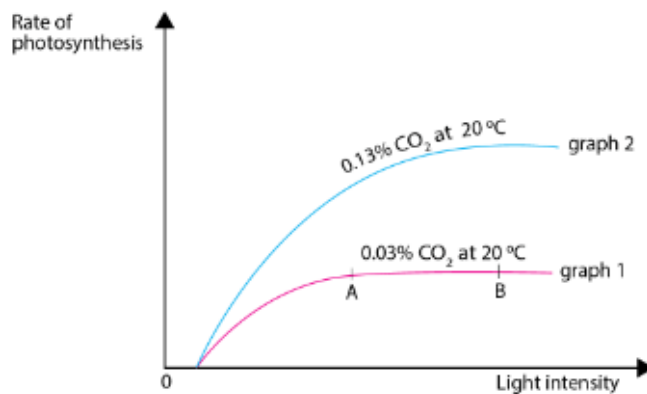


Figure 12.37 Effect of increasing carbon dioxide concentration on the rate of photosynthesis at 20 °C

Study Figure 12.38, increasing the temperature from 20 °C to 30 °C, while keeping the carbon dioxide concentration constant at 0.13%, causes a large increase in the rate of photosynthesis as shown in graph 3. Therefore, *the temperature of the surroundings is the limiting factor* in EF in graph 2.

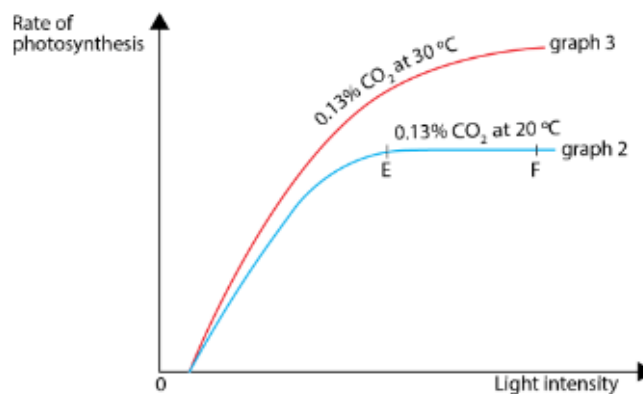


Figure 12.38 Effect of increasing temperature on the rate of photosynthesis at 0.13% CO₂

What Happens to the Glucose That Is Formed During Photosynthesis?

The glucose formed during photosynthesis is either used immediately or stored in the plant. This is summarised in Figure 12.39.

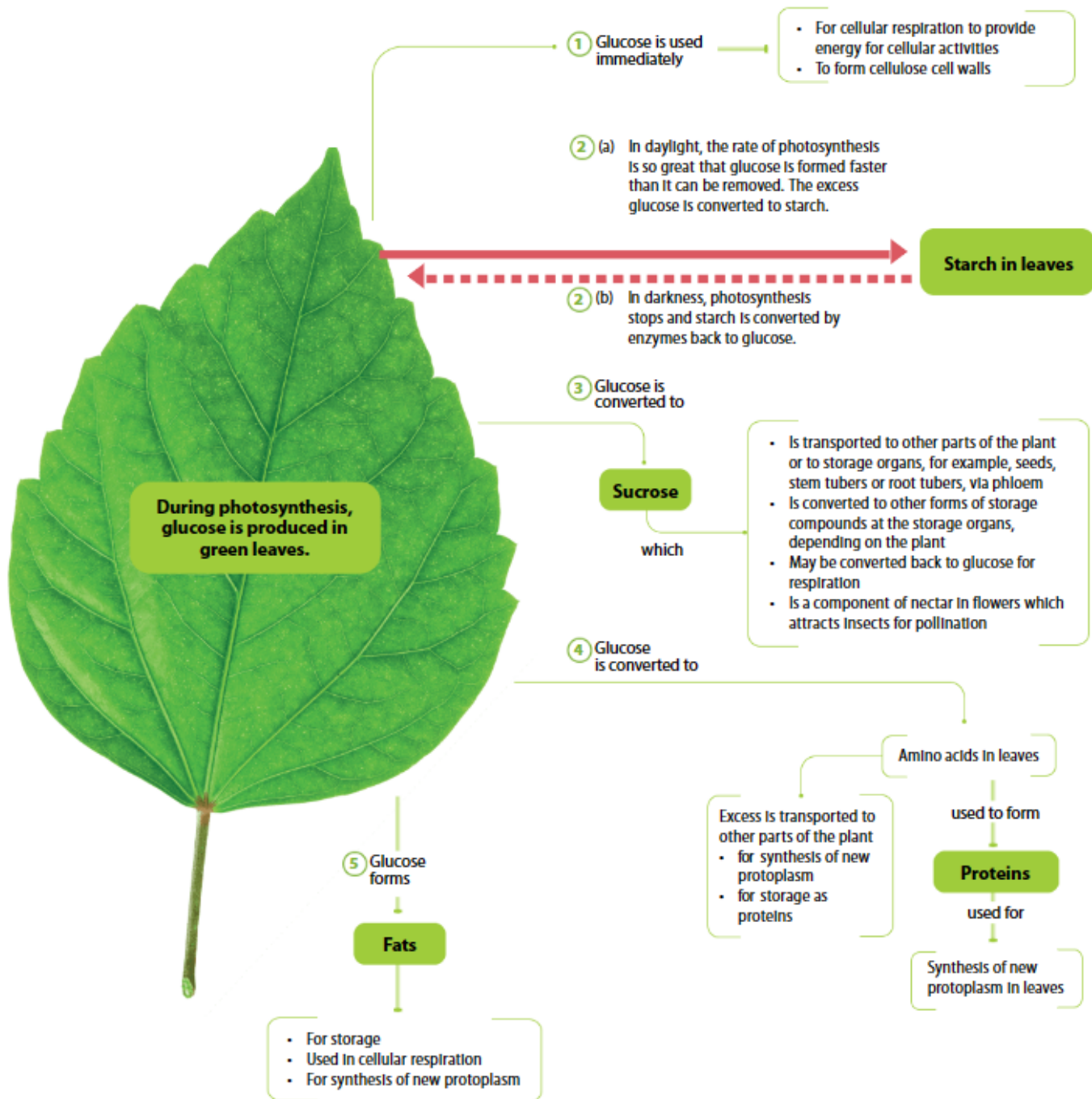


Figure 12.39 The fates of glucose in leaves

Why Is Photosynthesis Important?

Photosynthesis Makes Chemical Energy Available to Animals and Other Organisms

Sunlight is the ultimate source of energy for living organisms. During photosynthesis, chlorophyll absorbs energy from light and transfers it to chemical stores of energy in carbohydrate molecules. Fats, proteins and other organic compounds can be formed from carbohydrates. All these substances eventually become the food of other organisms (Figure 12.40). All organisms thus obtain chemical energy directly or indirectly from plants, because plants are the producers in food chains.



Figure 12.40 Organisms get their energy directly or indirectly from plants.

Photosynthesis Removes Carbon Dioxide and Provides Oxygen

Photosynthesis removes carbon dioxide from the air and at the same time, produces oxygen. The oxygen released is used by living organisms in respiration to release energy for cell activities. The process of photosynthesis maintains a constant level of oxygen and carbon dioxide in the atmosphere.

Energy Stored in Fossil Fuels Comes From Photosynthesis

All the energy in fossil fuels like coal, oil and gas, come from the sun, captured through photosynthesis. Burning of fossil fuels releases energy, which we use in our daily life such as in cooking and generating electricity in our homes.

Now, look at Figure 12.41. Give your views on the three statements made.



Link

Chemistry

We learn that photosynthesis helps to maintain air quality as part of the carbon cycle. The carbon cycle maintains the level of carbon dioxide in the atmosphere.



Link

Carbon dioxide is constantly removed from and released into the environment in the carbon cycle. Read more about this in Chapter 13.

Figure 12.41 Three people are discussing plants. Do you agree? Why or why not?

Let's Practise 12.3

- 1 Describe practical details to decolourise a leaf after it is plucked from a plant. Give a reason for each stage in your description.
- 2 A few drops of iodine solution were added to two decolourised leaves labelled A and B. The results of each leaf are shown in Figure 12.42.

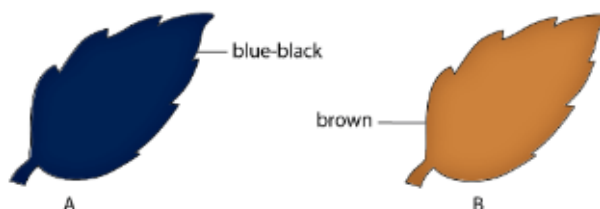


Figure 12.42

- (a) What treatment do you think the leaves were given before they were plucked from the plants?
 - (b) The experiment could have been used to show the need for a factor essential for photosynthesis. Name **one** such possible factor.
 - (c) Which leaf, A or B, could serve as a control for this experiment? Give your reason.
- 3 Table 12.3 shows the effect of light on the rate of photosynthesis for an aquatic plant, *Hydrilla*.

Table 12.3

Light Intensity/ Arbitrary Units	Rate of Photosynthesis / mg of Sugar Produced/ Area per Minute
20	10
30	20
40	25
50	32
60	41
70	55
80	70
90	70
100	70

- (a) Plot a graph to show the effect of light intensity on the rate of photosynthesis.
- (b) What is the relationship between the light intensity and the rate of photosynthesis up to 70 arbitrary units?
- (c) Why does increasing the light intensity above 80 arbitrary units **not** increase the rate of photosynthesis?
- (d) Suggest **two** ways of increasing the rate of photosynthesis. Explain your answer for each method you used.



Link

Theory Workbook
Worksheet 12C

12.4 How Can We Study the Movement of Substances in Plants?

Learning Outcome

- Define the term *translocation* as the transport of food (mainly sucrose) in the phloem tissue and illustrate the process through translocation studies.

Animals have a circulatory system that moves blood around their bodies in order to transport substances. Plants also have a way of moving water and dissolved substances around their bodies. With animals, we can measure pulses, but plants have no heartbeat. How then can we study the movement of water and food substances in plants?

How Can We Study the Path Water Takes Through a Plant?

Let's Investigate 12.10

Aim

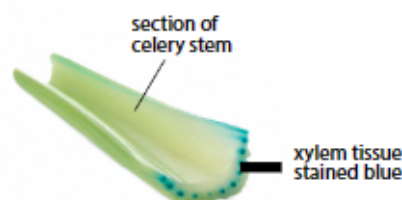
To investigate the path of water through a plant

Procedure

- Take a celery plant and wash it with water to remove the soil. A celery stem may be used for this experiment
- Allow the plant to stand with its stem immersed in methylene blue (or dilute red ink) solution (Figure 12.43).
- After a few hours, you can see that the blue dye has risen up the stem. Cut thin transverse sections of the stem.
- Place the sections on a glass slide. Examine the sections under a light microscope.
- Sketch the transverse section of the stem to show the distribution of the blue colour (methylene blue) in the main vein or the vascular bundle.

Observation and Conclusion

- Which tissue has been stained blue?
- What conclusion can you draw from your investigation?



methylene blue solution

celery



Figure 12.43 Experimental set-up to study the path of water through a plant



Disciplinary Idea

Systems

The plant's transport system ensures that its leaves receive sufficient raw materials for photosynthesis and that the entire plant subsequently receives the products of photosynthesis for growth.



Link

Practical Workbook
Experiment 12G

How Can We Study the Path Food Substances Take Through a Plant?

Bears often rub their bodies against the tree trunk. In doing so, they may rub off a complete ring of bark from the tree trunk. This is called girdling or ring-barking. Girdling results in the death of the tree over time. Humans practice girdling to remove trees in the forest (Figure 12.44). How does removal of a complete ring of bark result in the death of the tree? Evidence has shown that girdling removes the phloem tissue that transports manufactured food substances from the leaves to the roots.

► **Translocation** is the transport of manufactured food substances, such as sugars and amino acids, in plants.

What evidence is there to show that the transport of manufactured food substances occurs through the phloem?

Using the 'Ringing' Experiment

A ring of bark with the phloem is removed from the stem of a woody plant. After some time, the stem immediately above the cut region swells up. This is because with the phloem removed, food substances from the leaves cannot reach the stem below the cut region. They accumulate above the cut region, causing it to swell up (Figure 12.45).

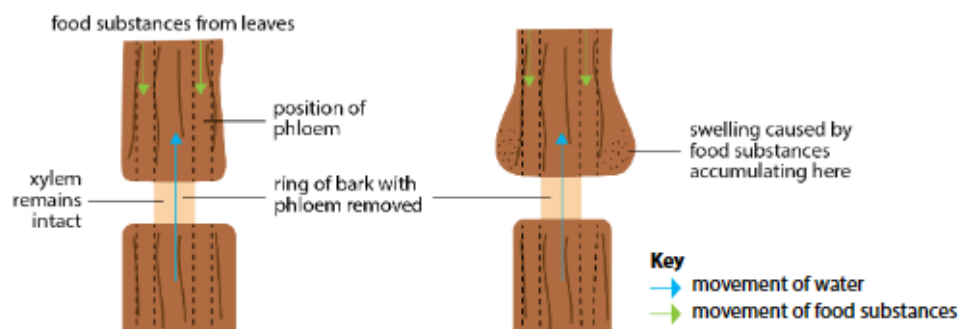


Figure 12.45 The 'ringing' experiment



Figure 12.44 Tree trunk with a ring of bark removed

Let's Investigate 12.11

Aim

To demonstrate the transport function of phloem (This experiment is also known as the "ringing" experiment.)

Procedure

- 1 Cut off a complete ring of bark including the phloem and cambium from the main stem of a woody twig (e.g. Hibiscus). This will leave the xylem exposed.
- 2 Place the twig in water with the cut ring above the water level (twig A). Set up a control using an unringed twig (twig B) as shown in Figure 12.46.
- 3 Observe the twigs daily. Note where roots or swellings appear. Sketch a diagram to show what happens to the region with the bark that has been removed.

Discussion

- 1 What does this experiment tell you about the phloem?
- 2 Suggest an explanation for your observations.

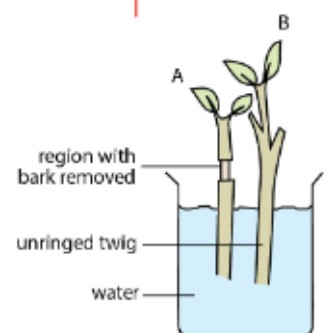


Figure 12.46 Experimental set-up of the "ringing" experiment

Using Aphids in Translocation Studies

Insects such as aphids feed on plant juices. The long mouthpart (stylet) of each aphid penetrates the leaf or stem. The aphid can be **anaesthetised** with carbon dioxide while it is feeding. The body of the aphid is then cut off, leaving only the feeding stylet in the plant tissues.

A liquid will exude from the cut end of the stylet. An analysis of this liquid shows that it contains sucrose and amino acids.

If the stem is sectioned and examined under the microscope, you will see that the feeding stylet of the aphid is inserted into the phloem sieve tube (Figure 12.47). This shows that translocation of sugars and amino acids occurs in the phloem.

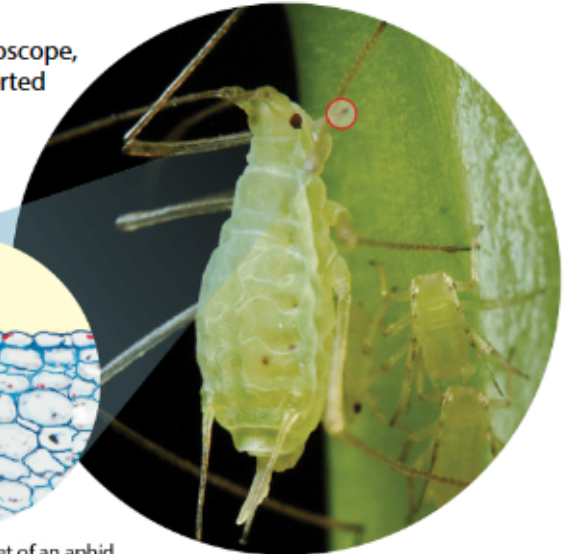
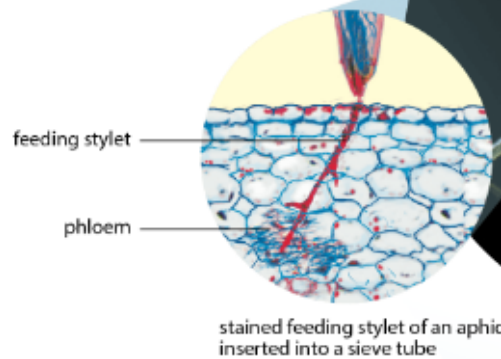
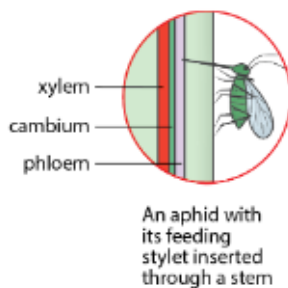


Figure 12.47 An aphid feeding

Using Isotopes in Translocation Studies

Carbon-14 (^{14}C) is a radioactive carbon isotope. Its presence can be detected by an X-ray photographic film.

A leaf is provided with carbon dioxide containing the radioactive carbon, ^{14}C . When photosynthesis takes place, the sugars formed will contain radioactive carbon. The stem is then cut and a section of it is exposed onto an X-ray photographic film. It is found that radioactive substances are present in the phloem (Figure 12.48), since radioactive substances cause the X-ray film to darken.

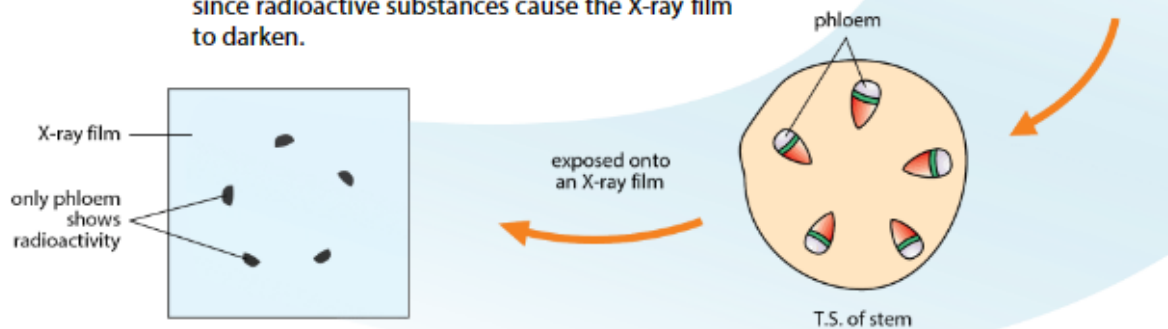


Figure 12.48 A simplified diagram showing the use of radioisotopes in translocation studies



Word Alert

Anaesthetised: to deprive of feeling or awareness.



Link

Theory Workbook
Worksheet 12D

Let's Practise 12.4

- 1 A Balsam plant has its roots immersed in a red dye. A and B in Figure 12.49 show the transverse sections of the leaf and stem.
 - (a) Which tissues would be most heavily stained by the dye on the following day?
 - (b) Which tissues carry amino acids in solution?
- 2 A ring of bark is removed from a leafy shoot, leaving the xylem exposed as shown in Figure 12.50. Draw a diagram to show the appearance of the stem a few weeks later.

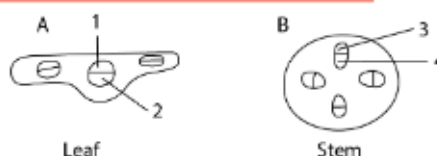


Figure 12.49

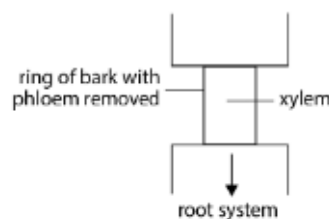


Figure 12.50

12.5 How Does Water Enter a Plant?

Learning Outcomes

- Explain how the structure of a root hair cell is suited for its function of water and ion uptake.
- Explain the movement of water between plant cells, and between them and the environment in terms of water potential.

When you water a plant, you pour water onto the area of the soil where the roots are, not where the flowers or leaves are. This is because water enters plants through the roots, but how do plants absorb the water from the soil?

Entry of Water into a Plant

Figures 12.51 and 12.52 show how water enters a plant. Water enters the plant through the root hairs. Ions or mineral salts also enter the plant through the root hairs.

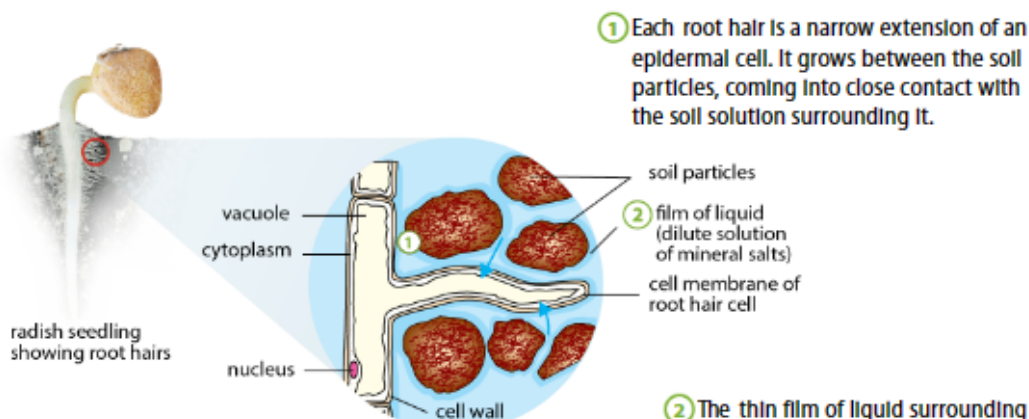
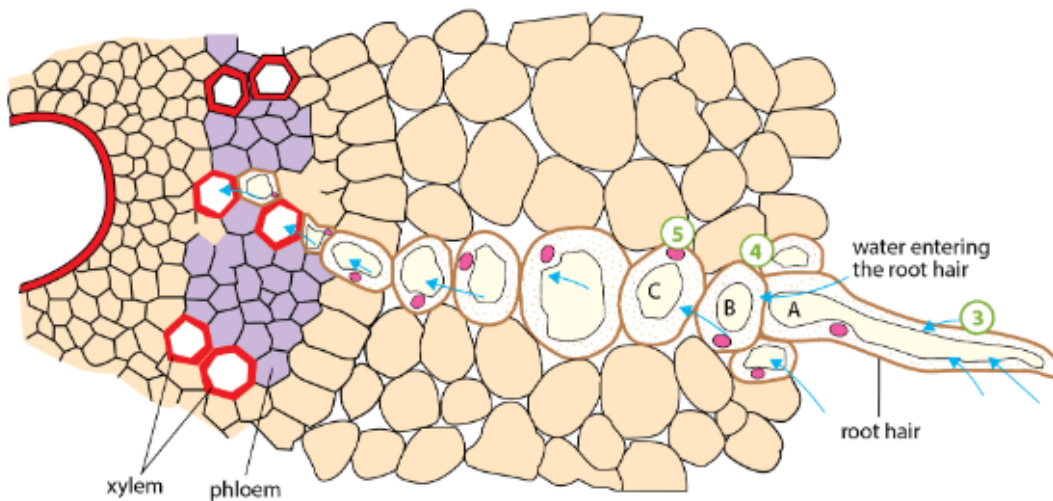


Figure 12.51 A section of a root hair cell

① Each root hair is a narrow extension of an epidermal cell. It grows between the soil particles, coming into close contact with the soil solution surrounding it.

② film of liquid (dilute solution of mineral salts)
cell membrane of root hair cell

② The thin film of liquid surrounding each soil particle is a dilute solution of mineral salts.



Link

Water potential moves water across partially permeable membranes. Recall what you have learnt in Chapter 2.

- ③ The cell sap in the root hair cell is a relatively concentrated solution of sugars and various salts. Thus, the cell sap has a lower water potential than the soil solution. The cell sap and the soil solution are separated by the partially permeable cell membrane of the root hair cell. Water enters the root hair by osmosis.
- ④ The entry of water dilutes the cell sap. The cell sap of the root hair cell (cell A) now has a higher water potential than that of the next cell (cell B). Hence, water passes by osmosis from the root hair cell into the inner cell.
- ⑤ Similarly, water passes from cell B into the next cell (cell C). This process continues until the water enters the xylem vessels and moves up the plant.

Figure 12.52 The path of water through the root



Tech Connect

A plant can draw water up from the roots. This occurs especially when it is photosynthesising and producing simple sugars as a result. The accumulation of sugars in the leaves causes a decrease in water potential. This causes water to move to the leaves and other parts of the plant by osmosis. Scientists have discovered that the changing water potential in the cell sap moves water from the xylem vessels to the cells in the leaf. Engineers have applied this knowledge to create an artificial pump that 'pulls' water through a microchip. They were able to mimic how a plant draws up water.

They discovered that the chip was able to passively pump water from the tank through the chip and out, at a constant flow rate for several days. Previously, it was not possible to do this continuously. It was also expensive to make instruments that pump water through such small devices.

The tree-on-a-chip thus features parts that represent:

- the xylem;
- the phloem;
- the selectively permeable membrane through which water flows as it travels by osmosis; and
- a bit of sugar to provide a concentration gradient.

This simple yet elegant design enables water to travel through the chip that can be used in small robots.

How Do Root Hairs Absorb Ions or Mineral Salts?

- By active transport, when the concentration of ions in the soil solution is lower than that in the root hair cell sap.
 - The root hairs have to absorb the ions against a concentration gradient, that is, by active transport (see Chapter 2).
 - The energy for this process comes from cellular respiration in the root hair cell.
- By diffusion, when the concentration of certain ions in the soil solution is higher than that in the root hair cell.

How Is the Root Hair Cell Adapted to Its Function of Absorption?

- The root hair is a long and narrow extension of the root hair cell. This increases the surface area-to-volume ratio which in turn increases the rate of absorption of water and mineral salts by the root hair cell.
- The cell membrane prevents the cell sap from leaking out. The cell sap contains sugars, amino acids and salts. It has a lower water potential than the soil solution. This results in water entering the root hair by osmosis.
- The root hair cell contains many mitochondria. Aerobic respiration in the mitochondria releases energy for the active transport of ions into the cell.



Link

Theory Workbook
Worksheet 12E

Let's Practise 12.5

- 1 Draw a fully labelled diagram of a root hair cell.
 - (a) By what process does water enter the root hair cell?
 - (b) State **two** conditions which must be present for this process to occur.
- 2 If you add a lot of soluble inorganic fertilisers to a potted plant, the plant will die. Suggest why.

12.6 How Does Water Move Up a Plant?

Learning Outcomes

- Define the term transpiration and explain that transpiration is a consequence of gaseous exchange in plants.
- Outline the pathway by which water is transported into the roots and through the xylem vessels to the leaves by transpiration pull.
- Investigate and explain the effects of variation of air movement, temperature, humidity and light intensity on transpiration rate.
- Investigate and explain how wilting occurs.

Water is taken in by the roots. The leaves at the top of the tree need water for photosynthesis. How does a tree get water to the leaves at the top? How does a tall tree, such as the *Seraya*, transport water from the roots to the leaves at the top of the tree? The main force that moves water up a plant is known as **transpirational pull** and is created from a process known as **transpiration**.

What Is Transpiration?

Green plants are continuously absorbing water from the soil. Not all the water absorbed will be used by the plant. Some water is removed when it evaporates from the **aerial** parts of the plant, i.e., from the leaves and stems.

- **Transpiration** is the loss of water vapour from the aerial parts of a plant, mainly through the stomata of the leaves.

How can we investigate the loss of water vapour from the aerial parts of a plant? Let's Investigate 12.12 and 12.13 help demonstrate that transpiration occurs mainly through the aerial parts of a plant.

Let's Investigate 12.12

Aim

To demonstrate transpiration in leaves and stems

Procedure

- 1 Take a potted plant and wrap a polythene bag around the pot and the stem of the plant. Water may evaporate from the soil surface. The bag prevents such water vapour from entering the bell jar in the set-up.
- 2 Place the pot on a glass plate and cover it with a dry bell jar (Figure 12.53).
- 3 Set up a control using similar apparatus but without a plant. Place the two set-ups side by side near an open window for two hours.

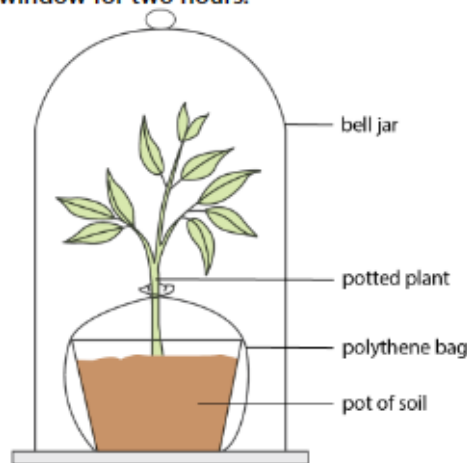


Figure 12.53 Experimental set-up to show transpiration in a potted plant

Observation and Discussion

- 1 What do you observe after two hours?
- 2 Test any liquid on the inside of the bell jar with anhydrous copper(II) sulfate. What do you observe? The anhydrous copper(II) sulfate will turn blue when it comes into contact with water. It is used to detect water or moisture.



Link

Physics

We learn that evaporation occurs when the molecules at the surface of a liquid escape into the atmosphere. Evaporation can occur at any temperature.



Word Alert

Aerial: above ground



Helpful Note

When a narrow tube is placed with one end in water, the water will spontaneously rise up the tube (Figure 12.54). This is called *capillary action*. Similarly, when you put the end of a piece of filter paper in water, the water will rise up the paper. Capillary action is one of the forces that helps water to rise up the plant from the roots to the stem.

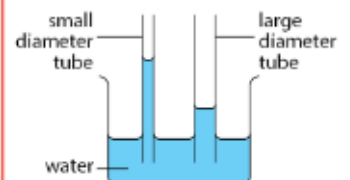


Figure 12.54 Water rising up capillary tubes with different diameters

Let's Investigate 12.13

Aim

To demonstrate that transpiration occurs mainly through the leaves

Procedure

- 1 Take two leafy twigs of about the same size from the same plant. Cut the end of each twig under water to prevent air from entering the xylem vessels. Any air trapped in the xylem vessels would interfere with the absorption of water by the twig.
- 2 Place each twig in a beaker of water and add a little oil to the water surface to prevent evaporation.
- 3 Strip off all the leaves of one twig and put petroleum jelly on the ends of the leaf stalks. Also put approximately the same amount of petroleum jelly on the stem of the leafy twig. Place each beaker under a large bell jar. Allow both twigs to stand where they can receive light (Figure 12.55).

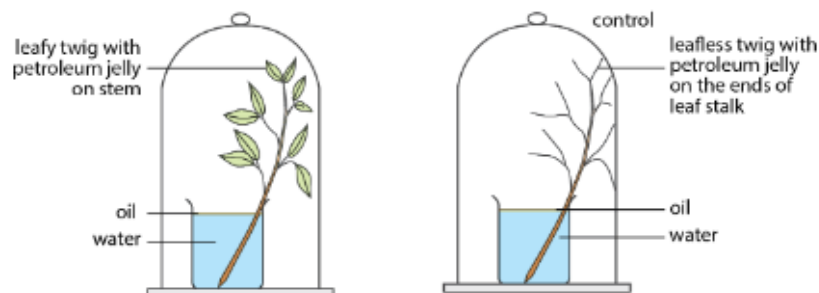


Figure 12.55 Experimental set-up to show transpiration occurs mainly through the leaves

Observation and Discussion

What do you observe after a few hours? Explain your observations.

You have now explored that transpiration occurs mainly through the leaves. Recall what you have learnt on the structures of the leaf in Section 12.1. On which surface of a leaf are stomata mostly found? How would this affect transpiration through the upper and lower surfaces of a leaf? Let us find out in Let's Investigate 12.14 and 12.15.

Let's Investigate 12.14

Aim

To compare the rate of transpiration of the upper and lower surface of a leaf

Procedure

This experiment uses cobalt chloride paper, which is an indicator for the presence of water vapour. Cobalt chloride paper is blue when dry and turns pink when it comes in contact with water vapour.

[Note: This experiment should be carried out on a warm, dry day. If the atmosphere is damp, e.g. early in the morning, the experiment may not be carried out successfully since the cobalt chloride papers will turn pink the moment they come into contact with damp air. In this case, cobalt thiocyanate papers may be used.]

- 1 Use a plant with stomata mainly on the lower surface of the leaves.

- 2 Place an intact leaf between two pieces of dry cobalt chloride paper. Then sandwich the leaf between two dry glass slides held in position by rubber bands as shown in Figure 12.56. The glass slides prevent the cobalt chloride paper from coming into contact with the water vapour in the air.
- 3 Place a ziplock bag over the leaf prepared in step 2. Seal as much of the opening as possible to minimise exposure to water vapour in the atmosphere.

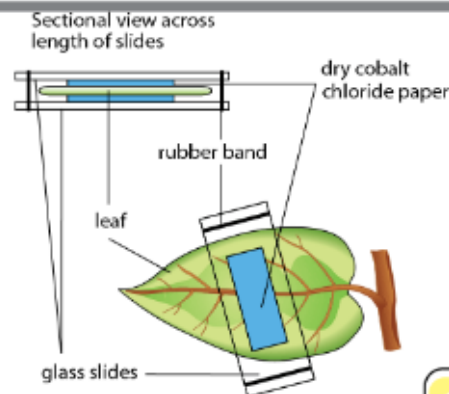


Figure 12.56 Comparing the rates of transpiration of the upper and lower surfaces of a leaf



Link

Practical Workbook
Experiment 12H

Observation and Discussion

What can you observe after a short while? What can you conclude from your observations?

Let's Investigate 12.15

Aim

To demonstrate that transpiration occurs largely through the stomata

Procedure

- 1 Choose leaves in which the stomata are mainly confined to the lower surface of the leaves. (Broad leaves of flowering plants normally have most of their stomata on the lower surface)
- 2 Take three fresh leaves of about the same size and surface area. Coat the leaf stalks with petroleum jelly to prevent loss of water by evaporation.
- 3 Treat the three leaves as follows:
 Leaf A — Cover the upper surface with a layer of petroleum jelly.
 Leaf B — Cover the lower surface with petroleum jelly.
 Leaf C — Cover both surfaces with petroleum jelly.
- 4 Use a balance to measure the mass of each leaf.
- 5 Hang the three leaves near the window where they can get some light.
- 6 After a few hours, note the condition of the three leaves.
- 7 Measure the mass of the three leaves again.

Observation and Discussion

Which leaf lost the most mass? Why?



Cool Career

Arborist

Do you wonder if trees need to be taken care of?

An arborist studies the structure and function of trees. Arborists are professionals that cultivate, manage, care for, and rehabilitate trees and shrubs. They remove dead branches and prune a tree when necessary (Figure 12.57). They monitor the health of the trees in their care and recommend treatment.

In Singapore, about 200 arborists from the National Parks Board look after about two million trees found in public spaces. They perform a basic check, looking out for things such as dead branches, which will decay and may fall during a storm.



Figure 12.57 An arborist using a handsaw to cut off a dead branch

How Is Transpiration Involved in Moving Water Against Gravity?

The evaporation of water from the leaves removes water from the xylem vessels (Figure 12.58). This results in a suction force which pulls water up the xylem vessels. *This suction force due to transpiration is known as transpiration pull.* It is the main force in drawing water and mineral salts up the plant.



Helpful Note

Transpiration pull is the main suction force that pulls water up the plant, aided by root pressure and capillary action.

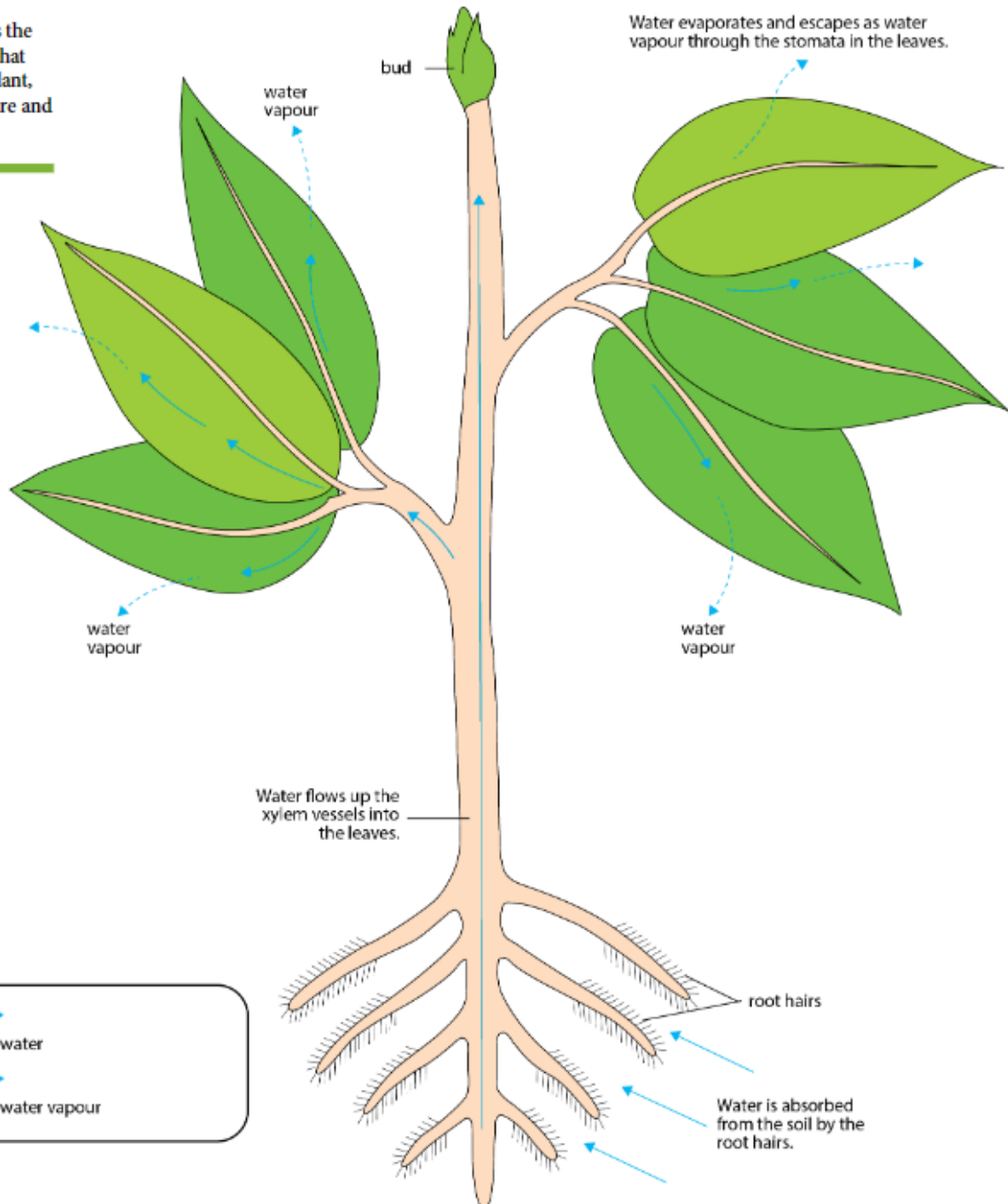


Figure 12.58 Movement of water in plants

Figure 12.59 shows the movement of water through the leaf during transpiration. Water evaporates from the surfaces of the mesophyll cells into air spaces and then diffuses out of the leaf through the stomata as water vapour.

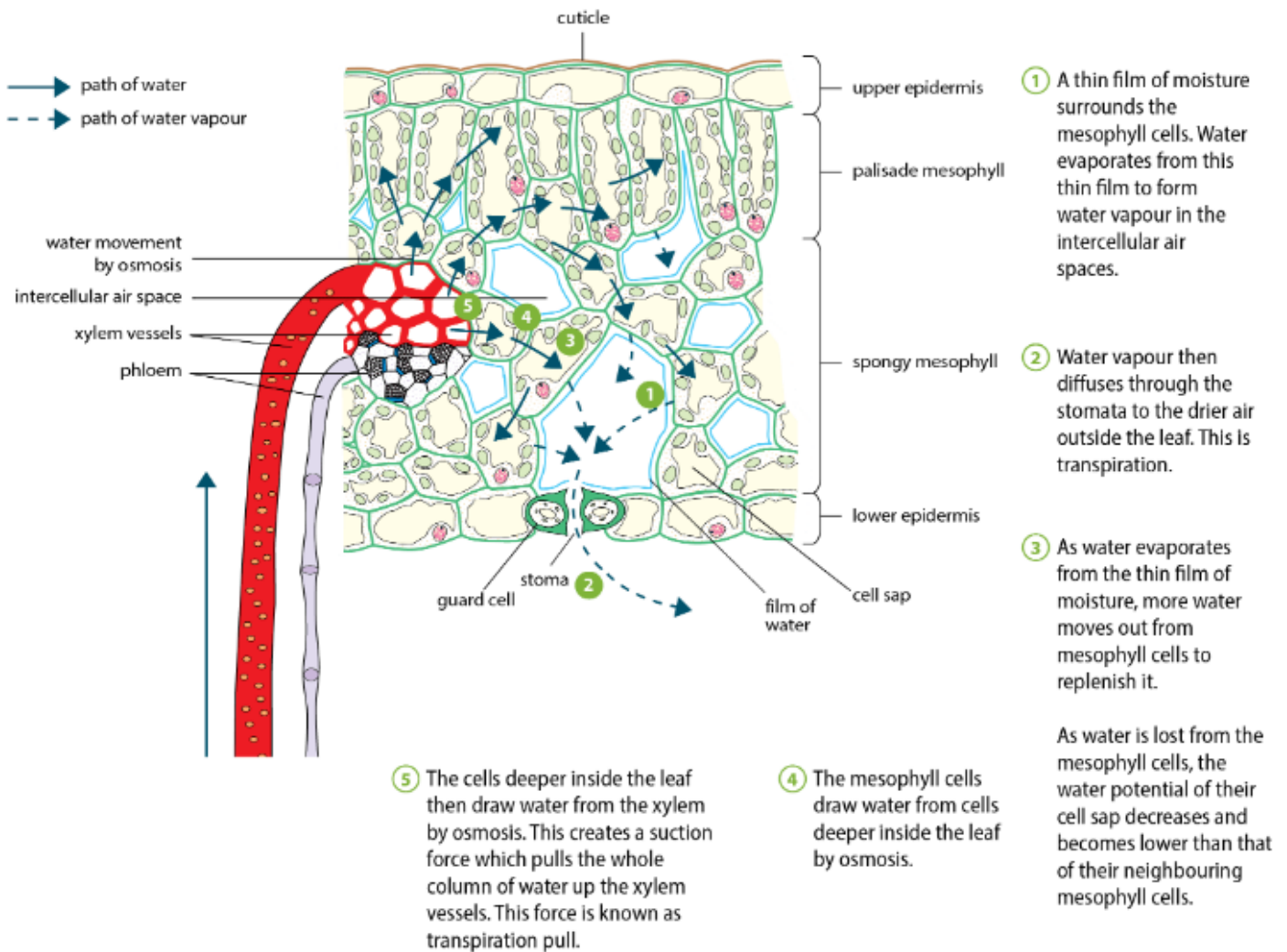


Figure 12.59 Movement of water inside a leaf

As transpiration occurs mainly through the stomata, it is linked to gas exchange between the plant and the environment. In daylight, stomata open to allow carbon dioxide to diffuse into the leaf for photosynthesis. Oxygen and water vapour are more concentrated in the intercellular air spaces, so they diffuse out of the leaf through the stomata.



The Importance of Transpiration

Although excessive transpiration is harmful to the plant, transpiration has certain uses:

- Transpiration pull draws water and mineral salts from the roots to the stems and leaves.
- Evaporation of water from the surface of cells in the leaves cools the plant, preventing it from being scorched by the hot sun.
- Water transported to the leaves can be used in photosynthesis, to keep cells turgid, and to replace water lost by the cells. Turgid cells keep the leaves spread out widely to trap light for photosynthesis.

Let's Investigate 12.16 and 12.17 show some ways of measuring the rate of transpiration. We can use these methods to find out how much water is lost from a plant or shoot during transpiration under different external conditions.

Let's Investigate 12.16

Aim

To demonstrate how the rate of transpiration of a shoot can be measured using a spring balance

Procedure

- 1 Cut a leafy shoot under water. Immerse the cut end in a test-tube of water and add a little oil to the water surface to prevent evaporation.
- 2 Tie a string to the mouth of the test-tube and measure the mass of the test-tube using a delicate spring balance as shown in Figure 12.60. Record the mass.
- 3 Place the test-tube in a test-tube rack near the window. After five hours, measure the mass of the test-tube and the shoot again. (The loss in mass is due to transpiration)
- 4 Calculate the rate of transpiration.
Mass of the tube with shoot (initial) = a g
Mass of tube with shoot after 5 hours = b g

$$\begin{aligned} \text{Rate of transpiration} &= \frac{\text{Loss in mass (g)}}{\text{Time taken (hours)}} \\ &= \frac{(a-b)}{5} \text{ g / hour} \end{aligned}$$

Give your measurements of mass and rate of transpiration to two significant figures.

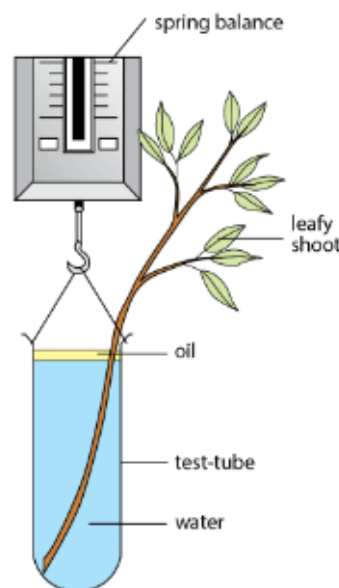


Figure 12.60 Experimental set-up to measure the rate of transpiration using a spring balance

Let's Investigate 12.17**Aim**

To demonstrate how the rate of transpiration of a potted plant can be measured under laboratory conditions

Procedure

- 1 Take a well-watered potted plant and wrap a polythene bag around the pot and the stem of the plant.
- 2 Use a balance to measure the mass of the potted plant. Then place it near the window in the laboratory. Measure the mass of the potted plant again after about five hours. The loss in mass is due to the loss of water vapour during transpiration.
- 3 Record your results and calculate the rate of transpiration of the plant under laboratory conditions.

Mass of potted plant (initial) = a g

Mass of potted plant after 5 hours = b g

$$\begin{aligned}\text{Rate of transpiration} &= \frac{\text{Loss in mass (g)}}{\text{Time taken (hours)}} \\ &= \frac{(a-b)}{5} \text{ g / hour}\end{aligned}$$

Give your measurements of mass and rate of transpiration to two significant figures.

How to Measure the Rate of Transpiration Under Different Conditions?

It is difficult to measure the rate of transpiration directly because some of the water taken in by the plant is used up in photosynthesis. The experiment in Let's Investigate 12.17 faces this limitation. However, the rate of water absorption can be measured directly. A potometer is used to measure the rate of absorption of water by the plant (Figure 12.61). Assuming that the rate of water absorption is proportional to the rate of transpiration, the potometer can then be used to measure the rate of transpiration.



Figure 12.61 A potometer can be used to measure the rate of transpiration

A shoot that is to be used in a potometer must be cut under water. The cut end is kept immersed in water for a few hours before use. This is to allow the shoot to adjust to the conditions in the potometer.

A potometer can also be used to determine the effect of different environmental conditions on the rate of transpiration. For example:

- to investigate the effect of temperature, we can compare the rate of transpiration in a room with an air conditioner, where the temperature can be controlled.
- to investigate the effect of wind speed, we can compare the rate of transpiration in a room with the ceiling fan switched on and switched off (in still air).
- to investigate the effect of light intensity, we can compare the rate of transpiration in a dark room with a table lamp at various distances from the plant.

Let's Investigate 12.18

Aim

To measure the rate of transpiration using a potometer

Procedure

- 1 To measure the rate of water absorption of a shoot, prepare the shoot as shown in Figure 12.62.

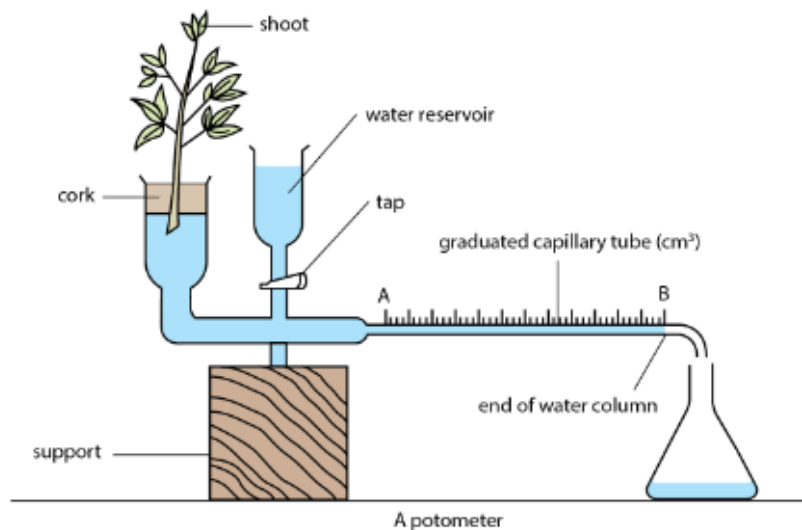


Figure 12.62 Experimental set-up to measure the rate of transpiration using a potometer

- 2 Insert the shoot through the hole in the cork of the potometer. Smear petroleum jelly around the region of the shoot that passes through the cork. This makes the apparatus airtight.

- 3 Open the tap of the reservoir to fill the graduated capillary tube with water.
- 4 Close the tap when the tube is full. As the shoot transpires, it absorbs water from the potometer to replace what was lost during transpiration. This causes the meniscus in the capillary tube to move from B to A. The rate of movement of the water column gives the rate of water absorption by the shoot.
- 5 Note the reading of the water column at B. Record the time taken for the end of the water column to move from B to A.
- 6 Calculate the rate of transpiration.
 Volume of water column from B to A = $a \text{ cm}^3$
 Time taken = b minutes

$$\text{Rate of transpiration} = \frac{a}{b} \text{ cm}^3 / \text{minute}$$

 Give your measurement of rate of transpiration to two significant figures.
- 7 The end of the water column can be pushed back to B by opening the tap of the reservoir to allow a little water to flow down. In this way, the apparatus can be reset. Several readings can be taken and the average rate of transpiration is calculated.

Discussion

In this experiment, we shall assume that the volume of water absorbed is the same as the volume lost through transpiration. Can you suggest the conditions under which these two rates will be different?



Link

Practical Workbook
Experiment 121

What Factors Affect the Rate of Transpiration?

Transpiration involves evaporation. Therefore, any factor that affects the rate of evaporation of water will affect the rate of transpiration. External factors that influence the rate of transpiration are air movement, temperature of the air, light and humidity.

Wind or Air Movement

In still air, water vapour that diffuses out of the leaf accumulates outside the stomata. This accumulation of water vapour makes the concentration gradient of water vapour inside and outside the leaf less steep. Thus, the rate of transpiration is lower.

However, if wind is present, water vapour that diffuses out of the leaf is blown away and does not accumulate. Thus, the concentration gradient of water vapour inside and outside the leaf is steeper and the rate of transpiration will be higher. The stronger the wind, the higher the rate of transpiration.

Temperature of the Air

Assuming that other factors remain constant, a rise in the temperature of the surroundings increases the rate of evaporation of water from the cell surfaces. Thus, the rate of transpiration is higher at higher temperatures.

Light

Light affects the size of the stomata on the leaf. It will therefore affect the rate of transpiration. *In the presence of light, the stomata open and become wider. This increases the rate of transpiration. In darkness, the stomata close, so less water is lost from the leaf.*

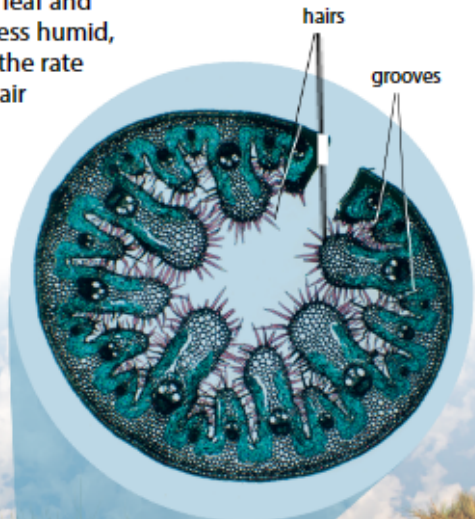
Humidity of the Air

The intercellular air spaces in the leaf are normally saturated with water vapour. There is a water vapour concentration gradient between the leaf and the surrounding air. When the air outside the leaf is drier or less humid, the concentration gradient of water vapour is steeper. Thus, the rate of transpiration will be faster. Increasing the humidity of the air will make the water vapour concentration gradient between the leaf and the surrounding air less steep. Thus, the rate of transpiration will decrease.

Plants living in dry conditions have special structures that help them to control their transpiration rate. An example is marram grass (Figure 12.63). The leaves of marram grass have sunken stomata that lie in grooves in the upper surface of the leaves (Figure 12.64). These grooves contain many tiny hairs that trap water vapour diffusing out of the stomata. This increases the humidity around the stomata and so reduces the rate of transpiration.

Figure 12.63
Wind-blown
marram grass

Figure 12.64 Stained
leaf cells of the
marram grass under
light microscope.



Now, look at Figure 12.65. Discuss the three statements made. Do you agree? Why or why not?



Figure 12.65 Three plant lovers are discussing transpiration. What are your views?

Wilting

The turgor pressure in the leaf mesophyll cells helps to support the leaf and keep it firm. This enables it to spread out widely to absorb light for photosynthesis. In strong light, when the rate of transpiration exceeds the rate of absorption of water by the roots, the cells lose their turgor. They become flaccid and the plant wilts (Figure 12.66, Diagram B). Wilting also occurs in the soft stems of some plants such as the Balsam. In this case, the cells of the stem lose water.

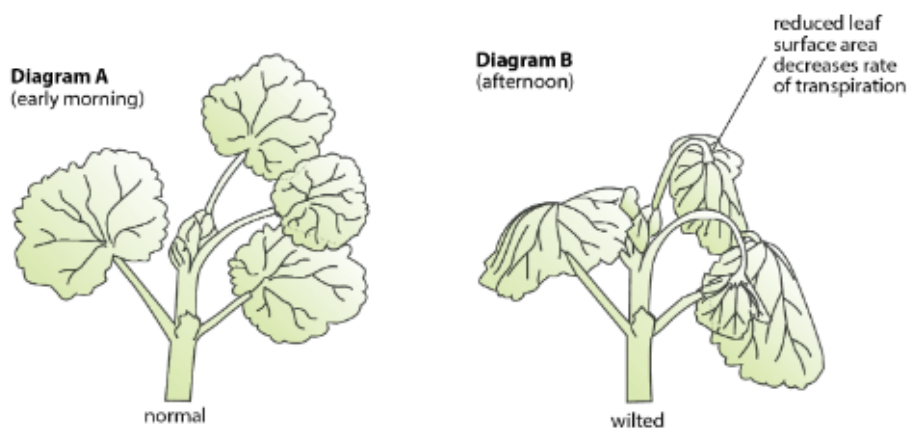


Figure 12.66 Parts of the same plant at different times of the day

Advantages of Wilting

When the leaf folds up due to wilting, the surface area that is exposed to light is reduced. Reduced exposed surface area of a leaf could reduce the exposure of stomata to the atmosphere and this reduces the rate of water loss through the stomata. Excessive loss of water causes the guard cells to become flaccid and the stomata to close. Thus, the rate of transpiration is reduced.

Disadvantages of Wilting

As the stomata are closed, the amount of carbon dioxide entering the leaf is also reduced. Carbon dioxide becomes a limiting factor and the rate of photosynthesis is decreased.

The folding of the leaf also reduces the surface area exposed to light. This also reduces the rate of photosynthesis.

Let's Practise 12.6

- 1 Figure 12.67 shows a cross-section of a leaf of a certain plant.
 - (a) In which habitat would you find such a plant?
 - (b) Explain how the leaf is adapted to help the plant survive in such a habitat.

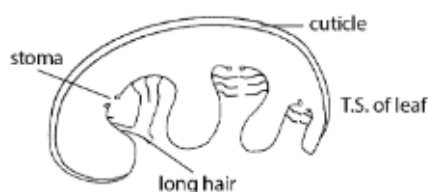


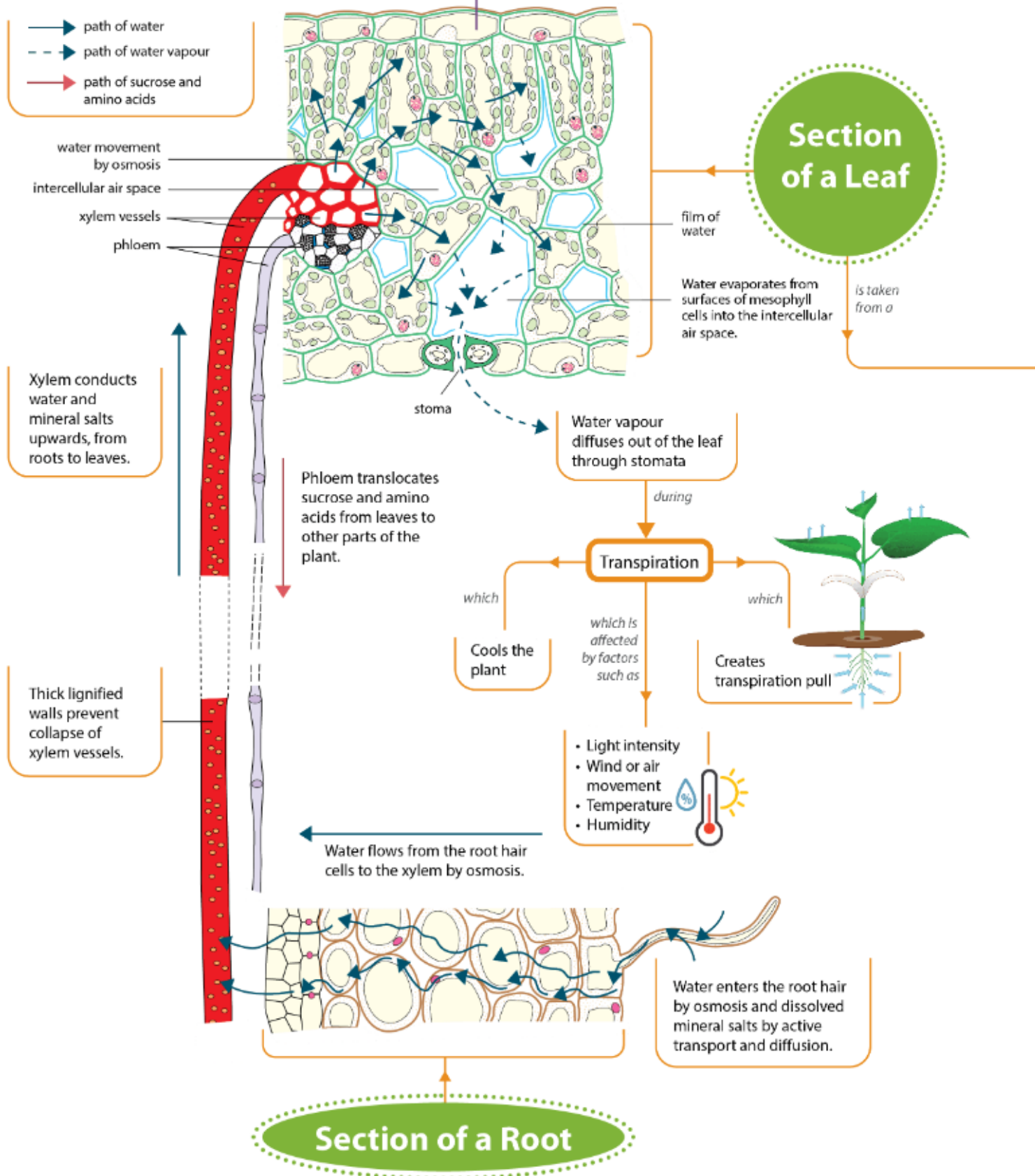
Figure 12.67

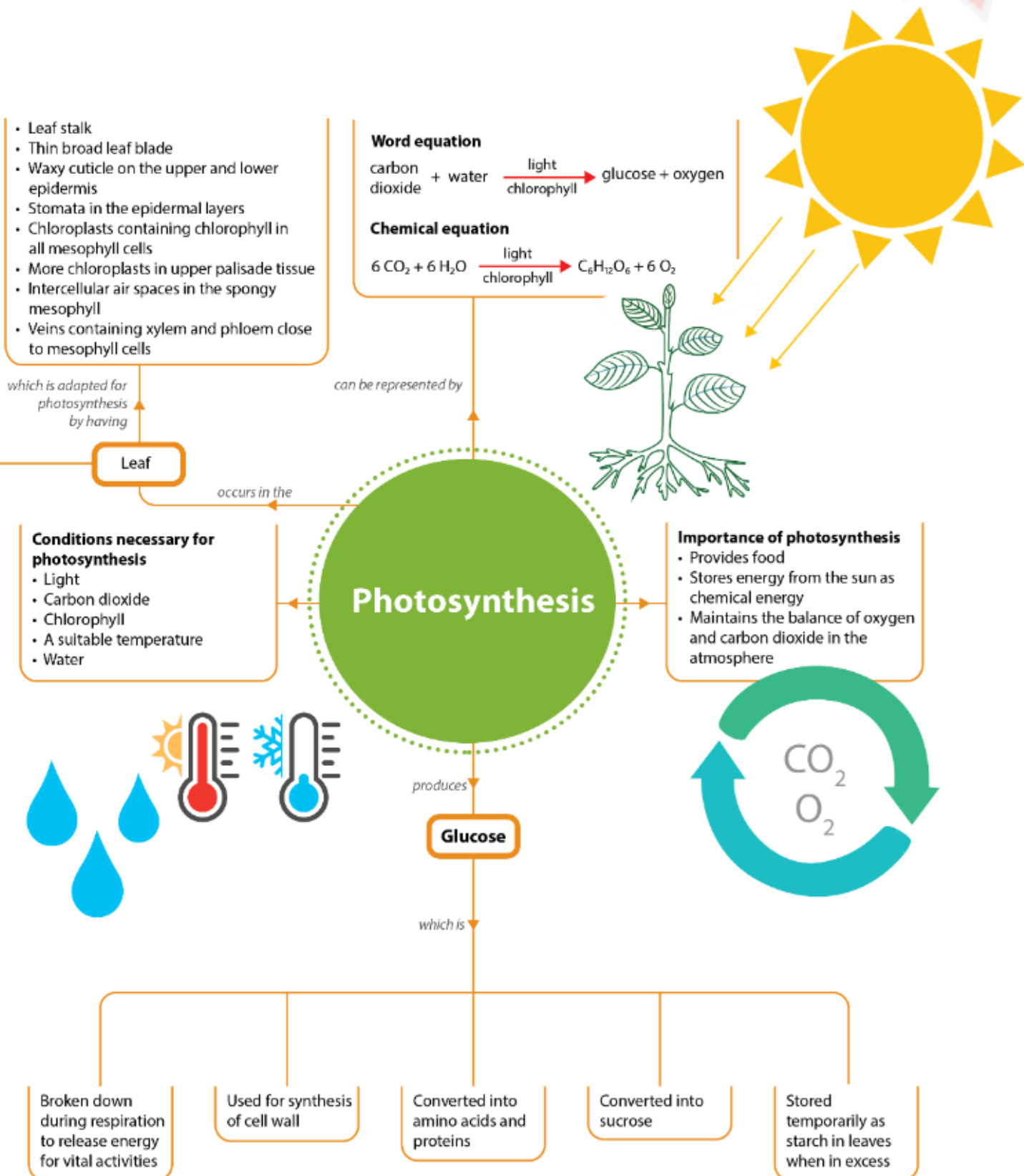


Link

Theory Workbook
Worksheets 12F–12G
Let's Assess
Let's Reflect

Let's Map It





Let's Review

Section A: Multiple-choice Questions

- 1 In which part of the leaf, **A**, **B**, **C** or **D**, can the cell in Figure 12.68 be found?

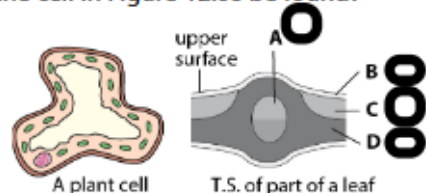
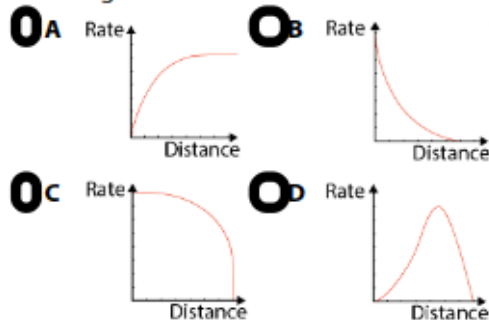


Figure 12.68

- 2 Which of the following graphs shows how the rate of photosynthesis varies with the distance between the plant and the light source?



- 3 Figure 12.69 shows the different tissues in a leaf. Which **two** numbered cells contain chloroplasts?

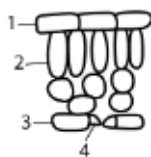


Figure 12.69

- 4 Which structure is involved in the uptake of mineral salts from the soil?
- A** cell membrane
B cell wall
C nucleus
D vacuole

- 5 The leaves of a plant were exposed to radioactive carbon dioxide. After a few hours in strong light, which tissue, **A**, **B**, **C** or **D**, in Figure 12.70, would become radioactive first?

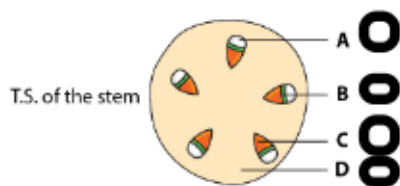


Figure 12.70

- 6 Figure 12.71 shows a transverse section and a longitudinal section of a plant. Which parts transport water and mineral salts?

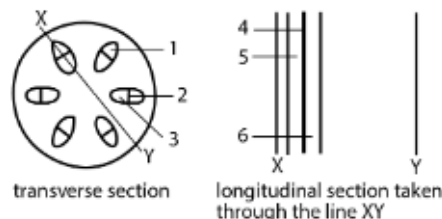


Figure 12.71

- A** 1 and 5
B 2 and 4
C 3 and 5
D 3 and 6
- 7 Anhydrous cobalt chloride papers were placed against both surfaces of a leaf. The paper on the lower surface of the leaf had a faster change of colour. This information shows that:
- A** there are more stomata on the lower surface than on the upper.
B the rate of transpiration is faster on the lower surface than on the upper surface.
C transpiration takes place through the stomata.
D the rate of transpiration is faster on the upper surface than on the lower surface.

- 8 Samples of sap were obtained from the phloem of stems and from the leaves of a plant. The concentration of sugar in both samples is shown in Figure 12.72.

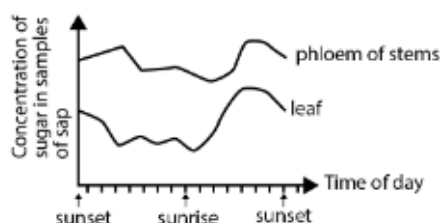


Figure 12.72

What is a possible conclusion for these results?

- ☐ A Photosynthesis takes place most rapidly in the leaves.
- ☐ B The amount of sugar is higher during the day than at night.
- ☐ C Sugar made in the leaves are translocated to the phloem in the stem.
- ☐ D Sugar is converted to starch stored in the leaves.

Section B: Structured Questions

- 1 Photosynthesis may be represented by the equation:



- (a) State **three** conditions necessary for photosynthesis that are not shown in the equation.
- (b) State **three** possible uses of the glucose formed in photosynthesis.

- 2 Study the graph in Figure 12.73.

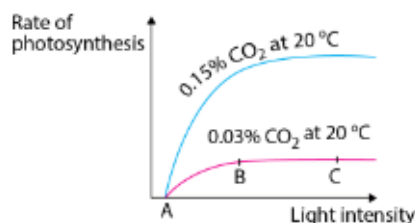


Figure 12.73

- (a) What factors limiting photosynthesis are shown in the graph?
- (b) What is the limiting factor in (i) AB and (ii) BC shown in the graph?

- (c) Name an internal factor of the leaf essential for photosynthesis that is **not** reflected in the graph.

- 3 Which gases, oxygen, carbon dioxide and water vapour, diffuse into and out of the stomata of a plant's leaves
- (a) on a warm, sunny day?
- (b) on a cool night?
- State the direction of each gas into and out of the stomata.

- 4 Figure 12.74 shows the appearance of the guard cells at night. Draw a diagram to show what they look like at:

- (a) mid-day
- (b) 1830 hours

Figure 12.74



- 5 Figure 12.75 shows a plant tissue seen in a transverse section of the stem.

- (a) What tissue is shown in A?

- (b) State **two** functions of this tissue. For each function state **one** way in which the tissue is adapted to the function.

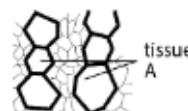


Figure 12.75

Section C: Free-response Questions

- 1 Explain how the leaf structure is adapted for the process of photosynthesis.
- 2 Explain how atmospheric carbon dioxide enters a leaf and becomes part of the glucose molecule in the leaf of a plant.
- 3 Explain how water is absorbed by the roots of a plant.
- 4 The concentration of salts in the cells of some seaweeds may be much higher than that of the seawater. Yet such plants are able to absorb salts from the seawater.
- (a) How do you think they are able to do this?
- (b) In what way is the process important to the life of seaweeds?

CHAPTER

13 Organisms and Their Environment



What You Will Learn



- How does energy flow through an ecosystem?
- What are ecological pyramids?
- How are nutrients recycled through an ecosystem?
- What are carbon sinks?
- How do we affect the ecosystem?
- Why is there a need for conservation?

Ants are such a common sight that they may seem almost insignificant. Is this really true? Imagine a world without ants. There would be no ant infestations in our houses and the amount of insecticides used would also be reduced.



Let us assume that for a brief moment that we manage to wipe out all the ants on the Earth. What role do ants play in the environment? How would their absence affect other organisms? How would our lives change in a world without ants? If someone told you that we would be at risk of dying of hunger if ants did not exist, would you believe him or her? Why?

13.1 How Does Energy Flow Through an Ecosystem?

Learning Outcomes

- Describe the non-cyclical nature of energy flow.
- Describe the roles of producers, consumers and decomposers in food chains and food webs.
- Explain how energy losses occur along food chains, and discuss the efficiency of energy transfer between trophic levels.

Nutrient and Energy Flow

The living organisms in any **ecosystem** can be categorised as **producers**, **consumers** or **decomposers**, based on their mode of nutrition. Energy and nutrients are transferred from producers to consumers to decomposers through feeding (Figure 13.1).

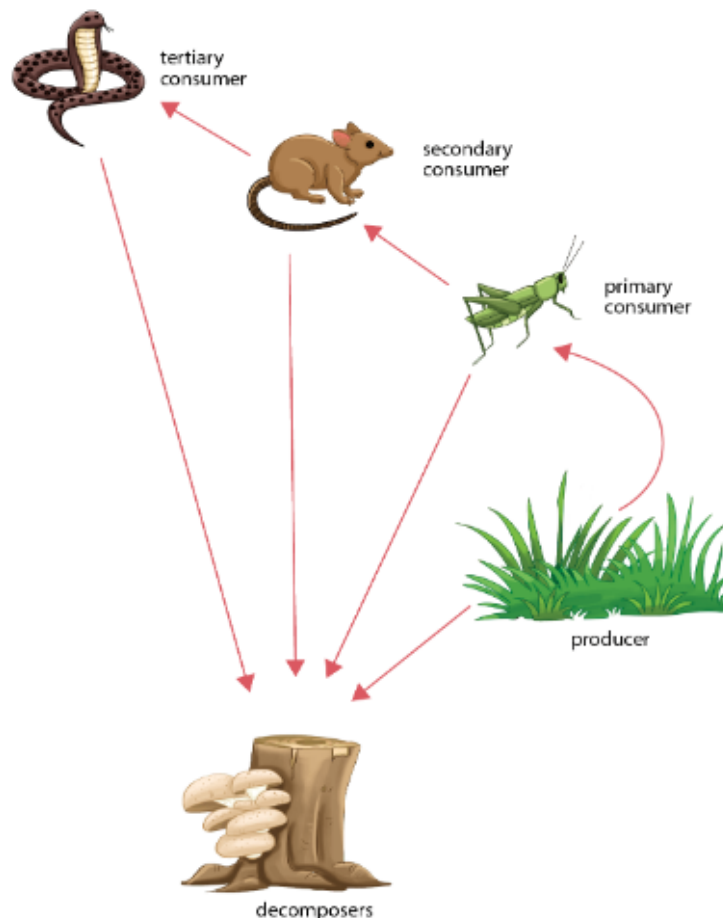


Figure 13.1 Relationship between producers, consumers and decomposers



Word Alert

Ecosystem: A community of organisms interacting with one another and with its non-living environment.



Disciplinary Idea

Systems

All living organisms are part of a complex network of interactions called the web of life. The interrelationships between living things and the environment include two major processes, the cycling of nutrients and flow of energy.



Link

What is photosynthesis?
What conditions are essential for photosynthesis to occur? Recall what you learnt in Chapter 12.

What Are Producers?

A **producer** is an organism that makes its own food. It contains chlorophyll that absorbs light to convert carbon dioxide and water into glucose, through a process known as photosynthesis. Glucose is a chemical store of energy. Oxygen is also released in the process. Examples of producers are plants and algae.

What Are Consumers?

Consumers are organisms that are not able to make their own food. They obtain energy and nutrients by feeding on other organisms. Consumers may be classified as primary, secondary and tertiary according to their position in a food chain (Table 13.1).

Table 13.1 Types of consumers

Primary Consumers	These are organisms that feed on plants only.
Secondary Consumers	These are organisms that feed on primary consumers.
Tertiary Consumers	These are organisms that feed on secondary consumers.

What Are Decomposers?

Decomposers are organisms that get their energy by breaking down dead organisms, faeces and excretory products. Their activities return nutrients like mineral salts to the environment. Examples of decomposers are bacteria and fungi (Figure 13.2).



Figure 13.2 Decomposers such as fungi break down dead organisms.



Helpful Note

The image below (Figure 13.3) shows how organisms interact with one another and their environment at various levels of organisation.

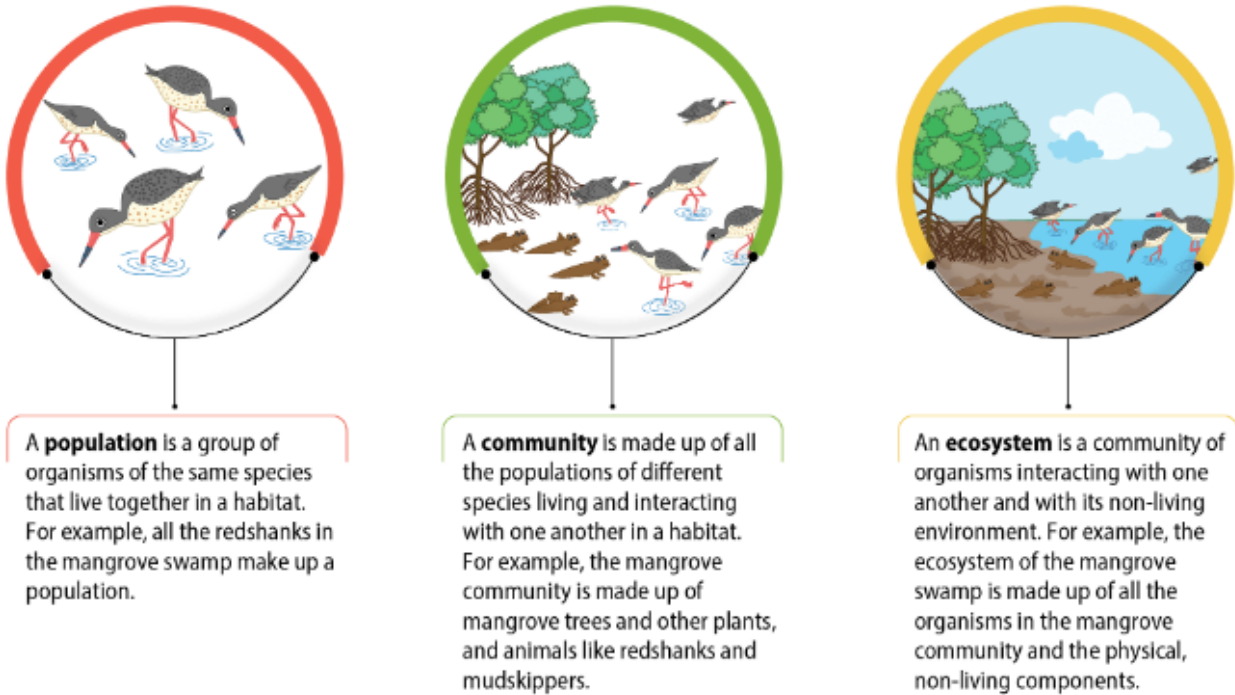


Figure 13.3 Organisms interact with one another and their environment.

Food Chains

- ▶ A **food chain** is a series of organisms, beginning with the producer, through which energy and nutrients are transferred.

We can represent the feeding relationships between organisms in an ecosystem using food chains. Each organism in a food chain feeds on the organism before it and provides food for the organism after it. A food chain always begins with a producer.

Below are some examples of food chains (Figure 13.4). Each arrow represents the flow of energy.

The position an organism occupies in a food chain is known as its **trophic level**. Generally, food chains do not have more than four trophic levels.

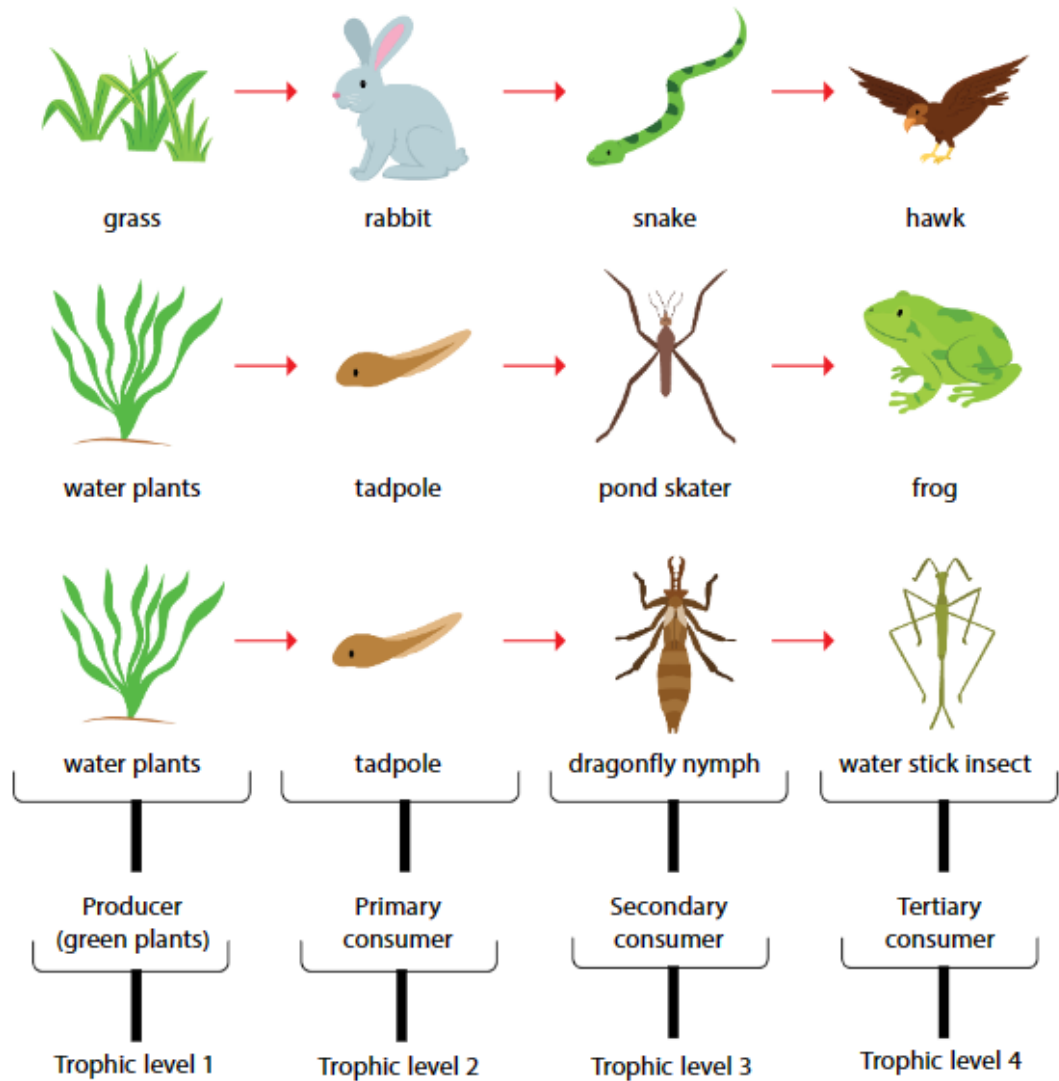


Figure 13.4 Examples of food chains

Food Webs

- A **food web** consists of a network of interconnected food chains.

Figure 13.5 shows a simple food web. Note that an organism can be at more than one trophic level in a food web.

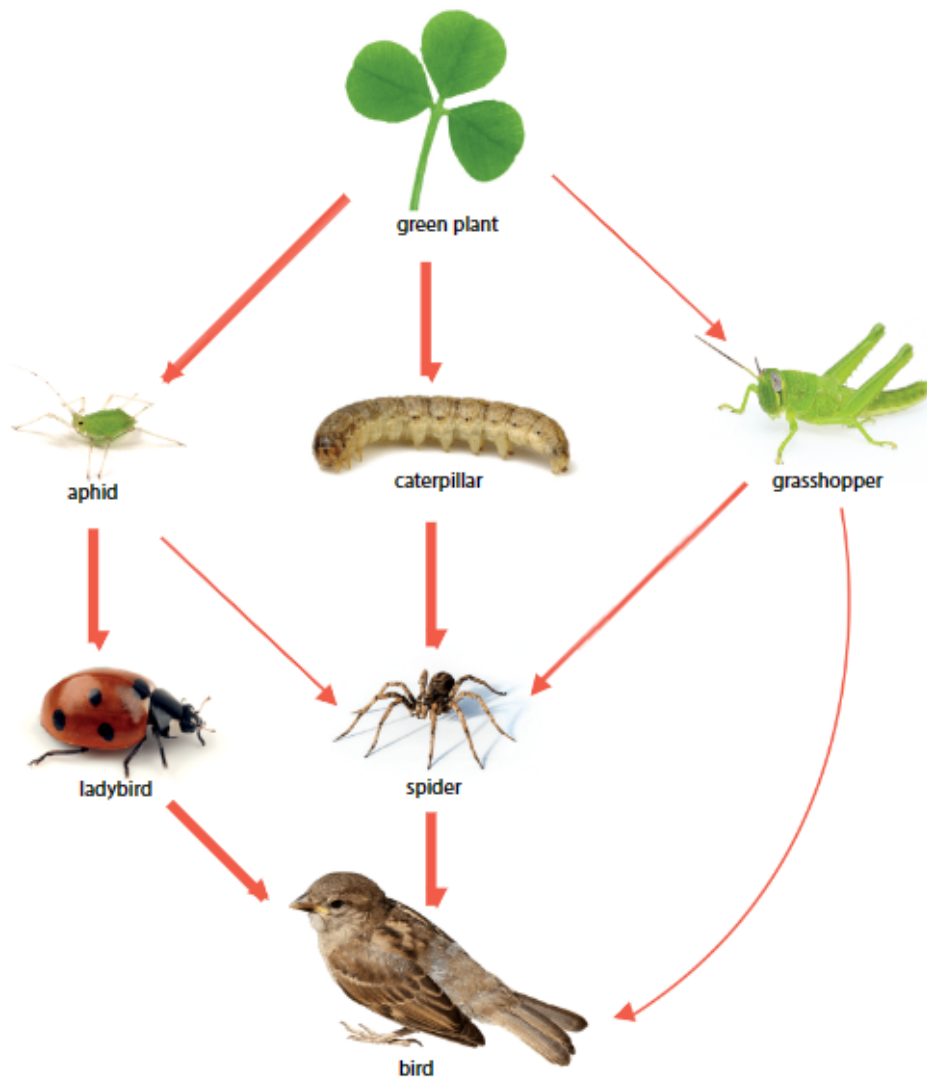
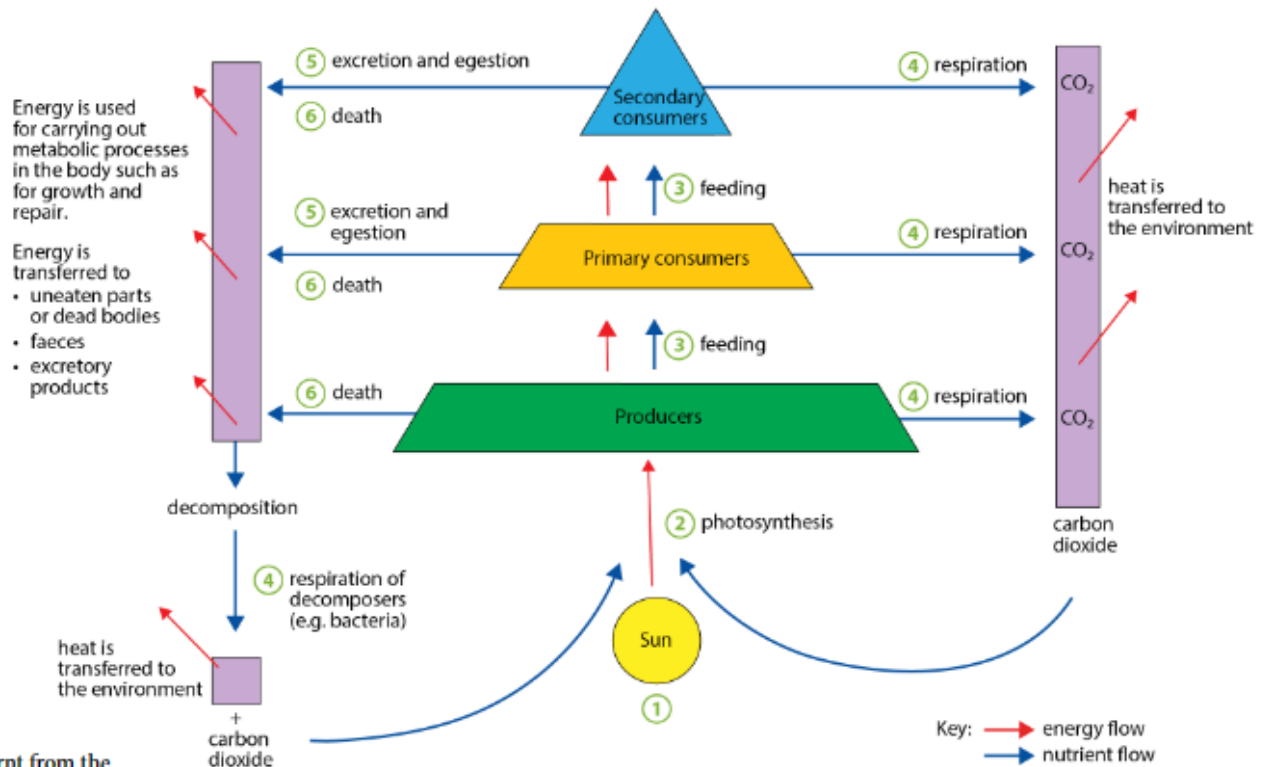


Figure 13.5 A food web

Non-cyclic Energy Flow in an Ecosystem

In an ecosystem, energy does not flow in a cycle. The energy flow is **non-cyclical** (linear). Figure 13.6 illustrates the flow of energy in the ecosystem and its relation to nutrition and respiration.

Living organisms cannot use heat to do work. They can only use light and chemical energy. Energy in the form of light has to be constantly supplied to the ecosystem. Hence, the Sun is the principal source of energy input to biological systems. The Sun provides energy in the form of light.



Link

Physics

We have learnt from the principle of conservation of energy, that energy cannot be created or destroyed, but can be transferred from one store to another. The total energy in an isolated system is constant. Living systems also follow the principle of conservation of energy. Energy changes form as it flows through the ecosystem. However, the total amount of energy in the system remains constant.

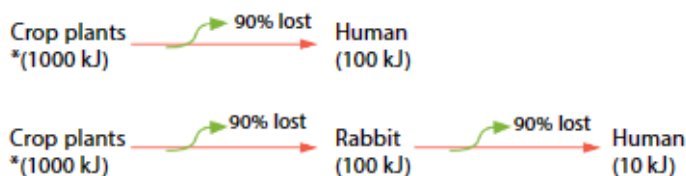
- 1 In any ecosystem, the principal source of energy is the Sun.
- 2 During photosynthesis, energy from the Sun is absorbed by chlorophyll in producers and transferred to chemical stores of energy in glucose molecules.
- 3 Energy In the producers is passed from one trophic level to another by feeding. The amount of energy at each trophic level decreases as it flows through the ecosystem because only some of the energy from one trophic level gets transferred to the next level.
- 4 The rest of the energy is largely transferred to the environment as heat, through respiration. Since this energy does not return to the same system as the organisms that produced it, it cannot be recycled in the ecosystem. Hence, the flow of energy through the ecosystem is non-cyclical.
- 5, 6 Egested and excreted materials, and dead organisms contain trapped chemical energy. This energy is released through the activity of decomposers. Decomposers use some of this trapped chemical energy for their needs. The rest of the energy is transferred as heat to the environment.

Figure 13.6 Energy flow and its relation to nutrition and respiration in the ecosystem

Short Food Chains Are More Efficient in Energy Transfer

A large amount of energy does not get passed from one trophic level to the next, as it is lost to the environment as heat, or transferred to uneaten body parts, faeces and excretory products. There will be less and less energy available for the organisms at the next trophic level as we move along the food chain. Hence, food chains are generally short. The shorter the food chain, the greater the amount of energy available to the final consumer, because less energy is transferred to the environment. We say that short food chains are more energy-efficient than long food chains.

For example, more energy will be available to a man if he feeds directly on the crop plants grown on a given area, rather than eating rabbits that feed on the crop plants grown on the same given area.



*Assume that 1000 kJ of energy was received by the producer.

As you can see, more energy is transferred or lost to the environment in a longer food chain than in a shorter food chain.

Why Do Food Chains Usually Have Fewer Than Five Trophic Levels?

Energy transfer along the food chain is inefficient. About 90% of the energy is lost as it is passed from one trophic level to the next.

- The energy is transferred to the environment as heat during respiration.
 - The energy is also transferred to uneaten body parts, faeces and excretory products.
- Hence, there is insufficient energy to support a long food chain.

Predator-prey Relationship

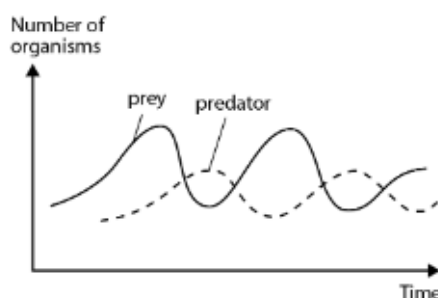
An animal that feeds on another animal is called a **predator**. An animal that is eaten by another animal is called the **prey**. For example, ospreys (also called sea hawks) eat fish, so ospreys are the predators of fish. Fish are the prey of ospreys (Figure 13.7).



Figure 13.7 An osprey hunts and feeds on fish.

The **fluctuation** in the populations of predators and prey can be illustrated by the graph in Figure 13.8.

Figure 13.8 Graph showing the fluctuating relationship between predator and prey populations



Word Alert

Fluctuation: irregular rise and fall in number or amount

An increase in the population size of the prey means that more food is available for the predators. This leads to an increase in the number of the predators, causing a decrease in the population of the prey. This in turn results in an inevitable decrease in the population of the predators as less food is available. The decrease in the number of the predators leads to an increase in the number of the prey.

This cycle of predator-prey relationship repeats over time. The increase and decrease in the population of the predators follow the corresponding increase and decrease in the population of the prey. The average size of the population of the prey is larger than that of the predator.

Although there are other factors involved, predation plays an important role in regulating natural populations.

An ecosystem uses both energy and inorganic nutrients. Energy enters an ecosystem in the form of light and heat from the Sun (Figure 13.9). Light from the Sun is transferred to chemical stores of energy in glucose molecules. The energy is then transferred from organism to organism through the ecosystem. Energy is transferred to the environment in the form of heat as it flows through the ecosystem. The energy that is transferred to the environment cannot be recycled. Hence, energy has to be constantly supplied to the ecosystem.



Figure 13.9 The Sun supplies energy to the Earth's ecosystem.

On the other hand, inorganic nutrients such as carbon and nitrogen need not be supplied from outside the ecosystem. They are obtained from the environment and they flow through the ecosystem in a cycle. Thus, in a balanced ecosystem, nutrients are not lost as they are continually recycled.



Link

Theory Workbook
Worksheet 13A

Let's Practise 13.1

- 1 From the food chain given, what are the trophic levels for aphid and snake?
green plant → aphid → spider → bird → snake
- 2 How does a food web provide more information than a food chain?
- 3 Name **three** ways by which energy is lost from a food chain to the environment.

13.2 What Are Ecological Pyramids?

Learning Outcome

- Describe and interpret pyramids of numbers and biomass.

Food and energy relationships can be shown using horizontal bar diagrams. The producers are placed at the bottom, the primary and secondary consumers in the middle, and the tertiary consumers at the top. Such diagrams form **ecological pyramids**. We can compare the trophic levels in food chains using ecological pyramids.

Figure 13.10 shows a food chain that can be used to construct ecological pyramids.

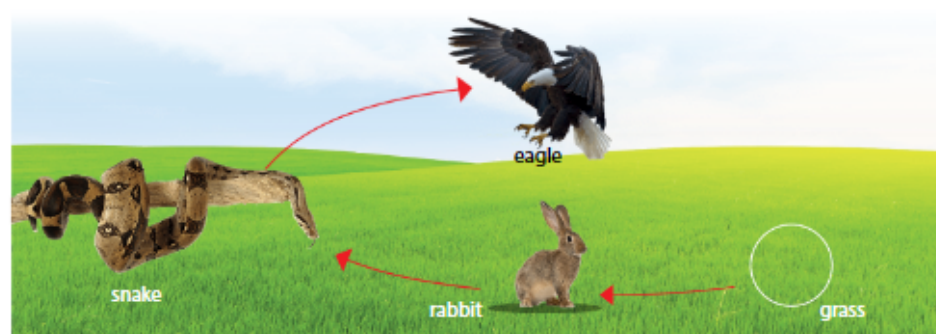


Figure 13.10 A food chain with four trophic levels

Pyramids of Numbers

A **pyramid of numbers** allows us to compare the *number of organisms* present in each trophic level at a particular time.

How Is a Pyramid of Numbers Constructed?

Consider the food chain: grass → rabbit → snake → eagle, shown in Figure 13.10.

Let us suppose that:

- There are ten eagles in a given area, and each eagle needs to feed on one snake every day. In a month, the ten eagles will need 300 snakes to keep them alive.
- If each snake eats two rabbits every day, 300 snakes will need 18 000 rabbits in a month.
- If each rabbit eats about 15 grass plants every day, 18 000 rabbits will need about 8 100 000 grass plants in a month.

The number of organisms in each trophic level can be used to construct a pyramid of numbers (Figure 13.11). The length of the bar in the pyramid represents the number of organisms present at that time. For this food chain, the pyramid will be broad at the base and narrow towards the top.

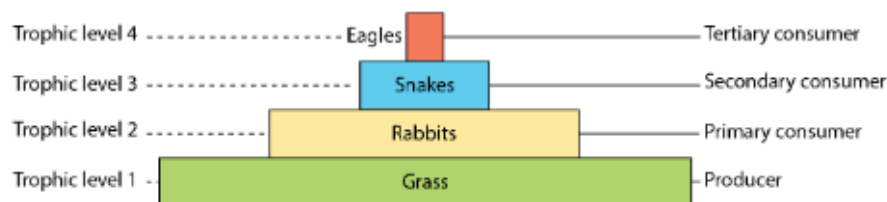


Figure 13.11 A pyramid of numbers

What Are Some Limitations of Using a Pyramid of Numbers to Represent a Food Chain?

- It does not consider the size and mass of organisms.
- It does not consider whether the organism is an adult or a **juvenile**.



Word Alert

Juvenile: a young organism

Pyramid of Biomass

A **pyramid of biomass** allows us to compare the *mass of organisms* present in each trophic level at a particular time.

How Is a Pyramid of Biomass Constructed?

The pyramid of biomass is constructed based on the standing mass — the *dry mass* of organisms in each trophic level *at any one time*. The dry mass of an organism is the mass of the organism when all its water has been removed.

Consider the food chain: grass → rabbit → snake → eagle, shown in Figure 13.10.

The biomass of the lower trophic level is larger than the biomass of the next trophic level (Figure 13.12).

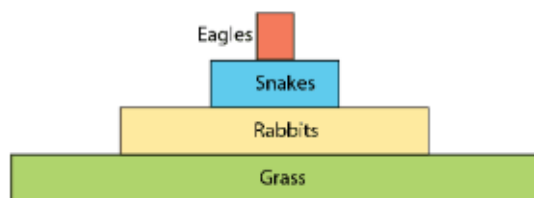


Figure 13.12
Pyramid of biomass

What Are Some Reasons for and Limitations of Using a Pyramid of Biomass to Represent a Food Chain?

There are reasons for, as well as limitations of, using a pyramid of biomass over using a pyramid of numbers (Table 13.2).

Table 13.2 Reasons for and limitations of using the pyramid of biomass

Reasons	Limitations
It considers the size and mass of organisms. Hence, it is a more accurate representation of energy flow through a food chain than a pyramid of numbers.	- Organisms have to be killed to obtain biomass. - It has to be constructed at a particular point in time.

Variations in Ecological Pyramids

Most ecological pyramids are pyramid-shaped, but there are exceptions. A pyramid of numbers may be upside down or inverted if:

- Organisms of one trophic level are parasitic on organisms of another trophic level.
- Many small organisms of one trophic level feed on a large organism of another trophic level.

Consider the following food chain: tree → bird → flea

In this case, the pyramid of numbers is inverted (Figure 13.13). The bottom of the pyramid is represented by only one tree. Many birds feed on the tree and many fleas are parasitic on the birds. However, the pyramid of biomass remains broad at the bottom and narrow towards the top (Figure 13.14). This is because one tree has a comparatively large biomass to support the other populations.



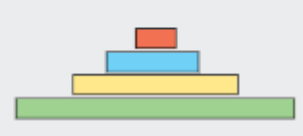
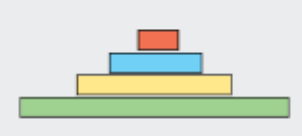
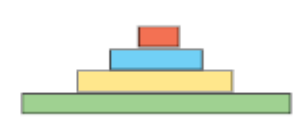
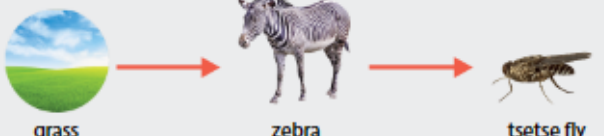
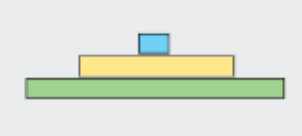
Figure 13.13 The pyramid of numbers is inverted.



Figure 13.14 The pyramid of biomass is not inverted.

More examples of variations in ecological pyramids are shown in Table 13.3.

Table 13.3 Some examples of food chains showing variations in ecological pyramids

Food Chain	Pyramid of Numbers	Pyramid of Biomass
 grass → rabbit → snake → eagle		
 tree → aphid → ladybird → small bird		
 grass → zebra → tsetse fly		

Now, look at Figure 13.15. Give your views on the three statements made.

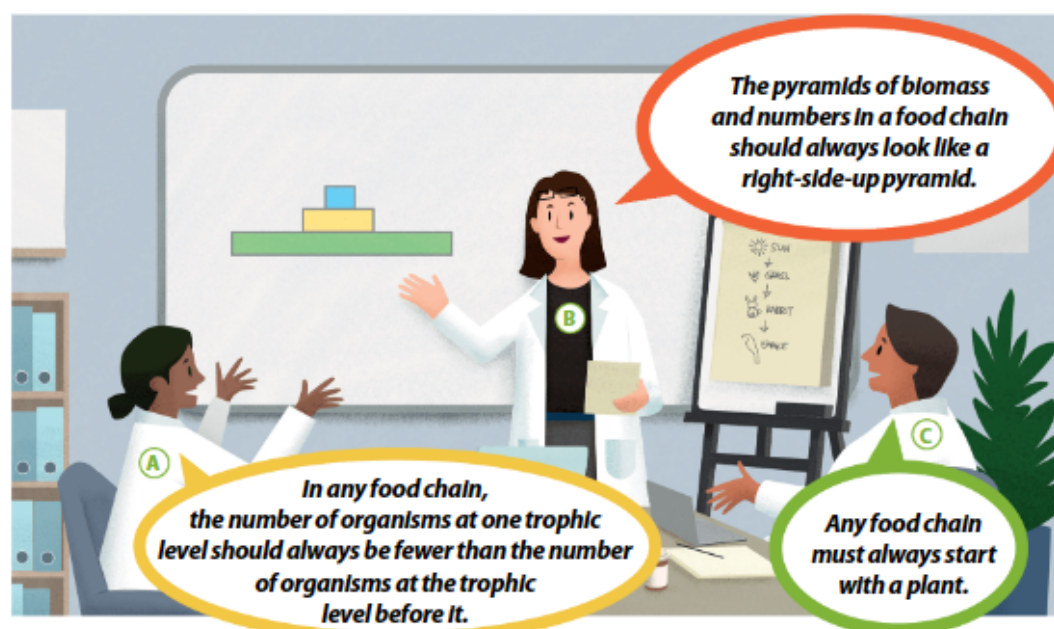


Figure 13.15 Three scientists discussing nutrient and energy flow in ecosystems

Let's Practise 13.2

- 1 Why is the pyramid of biomass a better representation of the energy flow through a food chain than a pyramid of numbers?



Link

Theory Workbook
Worksheet 13B

13.3 How Are Nutrients Recycled Through an Ecosystem?

Learning Outcome

- Describe how carbon is cycled within an ecosystem.



Disciplinary Idea

Energy

Energy is necessary to support the maintenance, growth and reproduction of all living organisms.

Plants as food producers absorb light from the sun to produce carbohydrates. Energy stored in carbohydrates is transferred, in a non-cyclical manner, to other living organisms through direct or indirect feeding relationships observed in food chains and webs.



Link

Do you remember how carbon dioxide is involved in respiration and photosynthesis? Recall what you learnt in Chapters 7 and 12.

Nutrient Cycling in an Ecosystem

Carbon, oxygen, nitrogen and water are essential substances in nutrients needed for life. In natural ecosystems, these substances are released back into the soil when organisms die. Decomposers, such as fungi and bacteria, break down dead organisms. In this way, materials locked up in the dead organisms can be returned to the physical environment, to be used again by green plants. Hence, in a balanced ecosystem, nutrients are never lost but are continuously recycled. The cycling of these nutrients is brought about by physical, chemical and biological processes.

Let's study the carbon cycle to understand the concept of nutrient cycling.

The Carbon Cycle

Carbon is constantly being removed from and released into the environment, in the form of carbon dioxide. Hence, the concentration of carbon dioxide in the environment remains relatively constant. The various processes by which carbon, in the form of carbon dioxide, is removed from and released into the environment make up the **carbon cycle** (Figure 13.16).

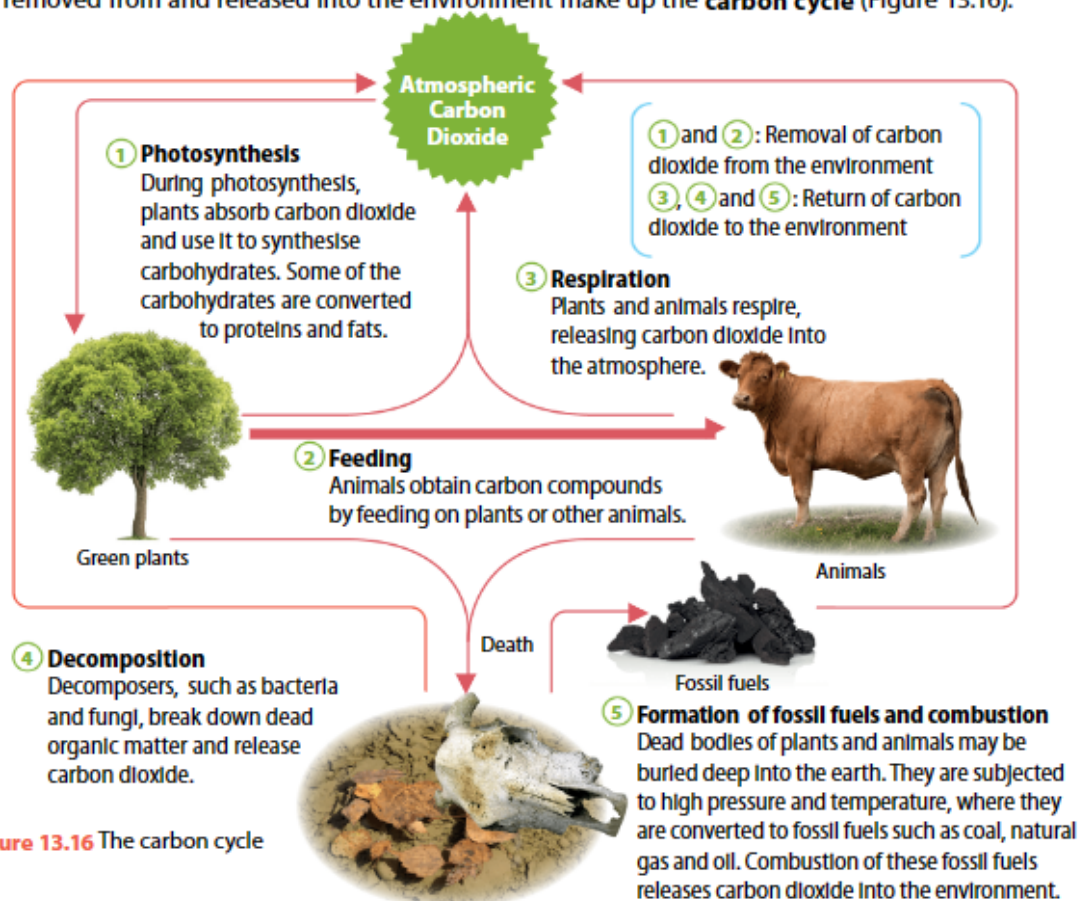


Figure 13.16 The carbon cycle

What Is the Importance of the Carbon Cycle?

The carbon cycle:

- ensures that there is a continuous supply of carbon dioxide for plants to carry out photosynthesis. Plants trap light during photosynthesis to synthesise glucose, which is a store of chemical energy.
- enables energy to flow through the ecosystem. Carbon compounds carry the stored energy from organism to organism in the food chains of an ecosystem.
- regulates the amount of carbon dioxide in the atmosphere.

Let's Practise 13.3

- 1 Figure 13.17 shows the flow of carbon compounds in the carbon cycle. The letters A, B, C and D represent carbon compounds in plants, animals, decomposers and the atmosphere. Assume that B represents plants, answer the following questions.

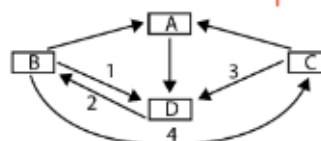


Figure 13.17

- State what each letter, A, C and D, represents.
- Name the processes represented by the numbers 1, 2, 3 and 4.
- Which processes, 1, 2, 3 or 4, do **not** return carbon dioxide to the atmosphere?
- Which process, 1, 2, 3 or 4, converts carbon from a simple form into another, more complex form?



Link

Theory Workbook
Worksheet 13C

13.4 What Are Carbon Sinks?

Learning Outcome

- Outline the role of forests and oceans as carbon sinks.

► A carbon sink is an area that stores carbon from the atmosphere for a long period of time. It stores more carbon than it releases.

In other words, a carbon sink is a carbon reservoir. The two main natural carbon sinks are forests and oceans. Carbon sinks remove carbon dioxide from the atmosphere.

Oceans as Carbon Sinks

Oceans are the largest carbon sinks on Earth (Figure 13.18). About one-third of the carbon dioxide released by human activities is absorbed by oceans.

The role of oceans as carbon sinks is driven by two processes, namely solubility and photosynthesis. The carbon dioxide that dissolves in the ocean's water is absorbed and used by aquatic plants in photosynthesis. A portion of the carbon compounds found in oceans is buried in the seabed and is in the form of fossil fuels such as natural gas and oil.

Figure 13.18 Oceans play a crucial role in absorbing carbon dioxide from the atmosphere.





Cool Career

Ecologist

Looking after the natural environment and caring for parks require people who love nature. Ecologists are specialist scientists involved in surveying ecosystems. They study the interrelationships between organisms and their environment. Ecologists collect and analyse data to assess habitats (Figure 13.21).



Figure 13.21 Two ecologists taking soil samples from a park

These specialists also study the impact humans have on the natural world. They recommend ways to minimise potentially harmful actions and solve environmental problems.

Forests as Carbon Sinks

Forests are also important carbon sinks. Atmospheric carbon dioxide is absorbed by the plants and used in photosynthesis (Figure 13.19). In forests, a large amount of carbon compounds is stored in trees. When trees die, their remains may be buried deep in the ground. After millions of years, these remains form coal, a type of fossil fuel. Studies of the Asian, African and South American tropical forests show that forests absorb about 20% of all the carbon dioxide released by the burning of fossil fuels.

Indiscriminate deforestation has damaging effects. Hence efficient forest management is important. Canada has about 10% of the world's forests. It claims that less than 0.5% of its forests are harvested in any given year. These harvested areas are allowed to regenerate into forests again (Figure 13.20).

The goal of the Paris Agreement is to keep the rise in global average temperature to below 2 °C. It aims to limit the temperature increase to 1.5 °C. This is expected to substantially reduce the effects of climate change. Carbon emissions should be reduced as soon as possible and reach net-zero by middle of the 21st century.

The Paris Agreement is an international treaty on climate change, which covers climate change mitigation, adaptation and finance. The Agreement was negotiated by 196 parties at the 2015 United Nations Climate Change Conference in France. Singapore signed the Paris Agreement on 22 April 2016. By November 2021, 193 members of the United Nations Framework Convention on Climate Change (UNFCCC) are parties to the Agreement.

Singapore launched a Climate Action Plan in July 2016. The Plan provides details of the strategies for adapting to the impact of climate change, such as implementing coastal and infrastructure protection measures. It also mentions ways to reduce carbon emissions up to 2030, such as improving energy efficiency, reducing carbon emissions from power generation and developing cutting-edge low-carbon technologies. These are the steps that have been drawn up in Singapore's climate pledge under the UNFCCC.



Figure 13.19 Trees use carbon dioxide during photosynthesis.

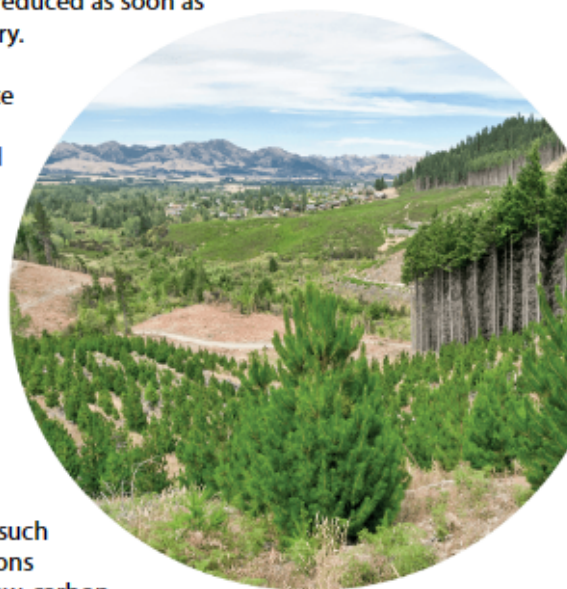


Figure 13.20 Young trees are planted near an older forest as part of a reforestation programme.

Let's Practise 13.4

- 1 What is a carbon sink?
- 2 Why are carbon sinks important? Suggest how the number of carbon sinks on Earth can be increased.

13.5 How Do We Affect the Ecosystem?

Learning Outcomes

- Describe how human activities, such as deforestation and use of fossil fuels, cause an increase in atmospheric carbon dioxide concentration, leading to global warming.
- Discuss how human actions can reduce the effects of global warming.
- Describe the effects of pollution caused by: sewage in water; plastic wastes in the marine environment; insecticides and their biomagnification up food chains, impacting top

carnivores.

You probably have a rubbish bin in your kitchen. Where does all the waste go, and what would happen if it were not removed? Would your kitchen and home end up buried under a mountain of rubbish, and be unfit for living? Earth is a limited resource and has limited space. It is also our home, and if we do not maintain it, we will ruin it.

Natural resources are resources supplied by nature. Air, water, soil, forests and wildlife are **renewable natural resources**. They can be replaced in the ecosystem by natural cycles as long as humans do not overuse them. On the other hand, natural resources such as fossil fuels take millions of years to form naturally. Since their formation takes millions of years, they cannot be replaced quickly enough. They are called **non-renewable natural resources**.

Human beings are continually using and **depleting** the Earth's natural resources. This upsets the balance of nature and causes lasting damage to the environment. The environmental damage caused is largely irreversible. Thus, human activities must be carefully planned and monitored to preserve and conserve the environment for the future.

In this section, you will learn about the effects some human activities have on the ecosystem (Figure 13.22). The extraction of natural resources may lead to habitat destruction, through deforestation and pollution (Figure 13.23).



Figure 13.22 Human activities can damage the environment.



Figure 13.23 Pollution from car exhaust and fumes from a chemical plant



Disciplinary Idea

Systems

Human activities can have positive and negative impact on the local and global environment, which are natural-occurring systems.



Word Alert

Depleting: reducing in number or quantity



These effects interrupt the food chains and food webs in the ecosystem. Through altering food chains and food webs, humans can have a negative impact on habitats.

An example that has a great effect on the habitat is deforestation.



Word Alert

Natural heritage:

all components of biodiversity, including flora and fauna, ecosystems and geological structures that have some special value for future generations

Deforestation

Before 1819, Singapore's population numbered about 150 villagers. There were very few houses and most of Singapore's land area was covered by swampy jungle and forests. As of 2021, the population is about 5.9 million people! Tall buildings have sprung up almost everywhere and roads cover Singapore's land area. Singapore is referred to as a 'concrete jungle'.

Although land is still being cleared in Singapore, there are areas of green spaces that are marked for conservation. These areas have large extent of greenery and natural heritage that should be conserved.

Why Are Forests Cleared?

The clearing of forests is known as **deforestation**. Forests are cleared to meet the increasing demands for land and materials such as wood (Figure 13.24). With modern technology, forests are cleared at a much faster rate than they can be replaced.



① Land is needed for urban development, for example, to build houses, roads and factories.



② Land is needed for growing crops such as rice.



③ Land is needed for farming livestock.



④ Firewood is a source of fuel.



⑤ Wood is used as construction materials, and turned into pulp for making paper.

Figure 13.24 Forests are cleared for land and raw materials.

What Are the Undesirable Effects of Deforestation?

Clearing forests for land and materials can have devastating effects on the local wildlife and environment, such as extinction and reduction in biodiversity. Deforestation can also have more far-reaching consequences. It can lead to an increase of carbon dioxide in the atmosphere, which contributes greatly to global warming.

Extinction and reduction in biodiversity

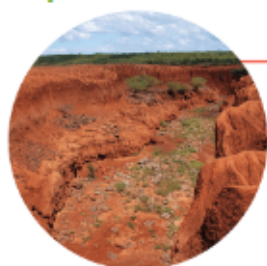
Clearing forests leads to habitat destruction for many species of animals. The remaining amount of forested land may not be big enough to support a breeding population of these animals. The animals may become endangered or extinct. This may result in a loss of biodiversity.

Global warming

When trees in the forests are growing, photosynthesis occurs at a higher rate than respiration. The excess carbon is stored in tree trunks, roots and in the soil. When trees in the forests are cut down, they release into the atmosphere all the carbon dioxide they have been storing. Further emissions of carbon dioxide are created when the trees are left to rot on the forest floor or when they are burnt. Carbon dioxide is the most commonly produced greenhouse gas. Deforestation will result in the decrease in the number of trees which function to remove carbon dioxide from the atmosphere through the process of photosynthesis. Hence, the concentration of carbon dioxide in the atmosphere will increase, leading to global warming.



Helpful Note



Deforestation causes soil erosion. The leafy canopy of the trees in forests protects the soil from the impact of the falling rain. When trees are removed, the soil is directly exposed to the force of the rain. There are also no roots to bind the soil. The topsoil, the most fertile layer, is eroded (gets washed away) during heavy rains, especially if the rain falls on steep slopes.

Soil erosion due to deforestation can lead to floods. The eroded soil may be deposited in rivers and streams, blocking the flow of water. The water levels in rivers rise rapidly, causing floods.



When forests are cleared, the leafy canopy of trees no longer exists. Sunlight falls directly onto the soil. Water evaporates rapidly from the soil, causing it to harden. The land becomes barren, and plants cannot grow in the soil. This is known as desertification. The survival of organisms that depend directly or indirectly on plants for food are also threatened.



Link

Chemistry

We learn that combustion is one way of extracting useful energy from fuels. We also learn that plastics are formed by polymerisation. As most plastics are non-biodegradable, environmental problems arise when these plastics are disposed of.

Effect of Human Activities on Global Warming

Human activities that cause an increase in carbon dioxide concentration in the atmosphere, leading to global warming include:

- Deforestation: Without the trees to absorb atmospheric carbon dioxide for photosynthesis, the concentration of carbon dioxide in the atmosphere will increase. Annual rainfall in the area will decrease.
- Combustion of fossil fuels like coal and gas
- Combustion of plastic waste
- Emission from motor vehicles

Effects of Carbon Dioxide Pollution

• Greenhouse effect

Carbon dioxide is a greenhouse gas. It forms a layer over Earth's surface. Heat is trapped within this layer around Earth. This is the greenhouse effect that causes global warming. An enhanced greenhouse effect may result in climate change. Ice sheets in Greenland and Antarctica may melt. Sea levels may rise, causing flooding in some countries.

The rise in seawater temperature may result in a loss of biodiversity. For example, it causes coral bleaching and death of corals in coral reefs (Figure 13.25). Coral reefs provide a habitat for a large variety of marine organisms. Corals rely on colourful algae which live in their tissue and produce food for the corals. When corals are stressed by changes in light, water or temperature, they expel the algae that live in them and turn white. This process is known as coral bleaching. Corals that have been bleached lose their ability to support as many species, leading to a loss in biodiversity.

Figure 13.25 Coral bleaching takes place when sea surface temperatures rise.



Rising atmospheric temperatures and extreme weather such as floods could mean more breeding grounds for mosquitoes. More outbreaks of mosquito-borne diseases such as dengue could occur.



Helpful Note

Singapore uses Wolbachia-Aedes suppression technology to control the spread of dengue, a mosquito-borne disease. The Wolbachia bacteria is found naturally in some mosquito species. The National Environment Agency of Singapore (NEA) breeds a large number of male Aedes mosquitoes that carry the Wolbachia bacteria, and regularly releases them into the environment (Figure 13.26). When these mosquitoes mate with the urban female Aedes mosquitoes that spread dengue, the eggs produced do not hatch. Hence, no offspring are produced. This leads to a decline in the population of Aedes mosquitoes and a decline in dengue cases.

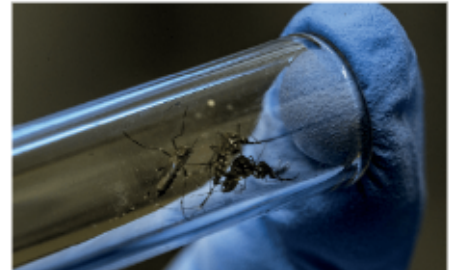


Figure 13.26 Aedes mosquito infected with Wolbachia bacteria in a test-tube

- **Effect on aquatic ecosystems**

High atmospheric carbon dioxide concentrations affects the aquatic ecosystems. More atmospheric carbon dioxide dissolves in the sea water which becomes more acidic. The acid dissolves calcium compounds in the shells of shellfish (Figure 13.27). This weakens their shells, making them more vulnerable to predators.



Figure 13.27 Shellfish may produce thinner shells that may be prone to fracture.

Difference Between Global Warming and Climate Change

Global warming is the rise in global temperature. This process is accelerated by human activities that cause increasing concentrations of greenhouse gases, such as carbon dioxide, in the atmosphere.

Climate change refers to the changes in temperature and weather patterns over a long period of time. The effects of climate change include rising sea levels, melting of ice sheets in Greenland and Antarctica (Figure 13.28), shifts in flowering or plant blooming times and unpredictable weather changes. In some countries, there may be more frequent and intense hurricanes and winter storms.



Figure 13.28
Melting ice sheets in the polar region



Tech Connect

Climate change is a real problem that is affecting many parts of the world today. In recent years, scientists and engineers have focused on slowing down climate change. This has led to the discovery of a type of technology called Green Technology.

In 2017, the United Nations Environment Programme identified eight main areas where scientists and engineers could develop green technologies. Here are five of those areas:

- designing lighting equipment that consumes less energy;
- designing buildings that do not demand large amounts of energy to maintain;
- managing the use of energy, especially in a building;
- developing energy-efficient devices in information and communications technology;
- moving towards electric passenger transportation vehicles such as cars and trains (Figure 13.29).

Based on your understanding of the causes of climate change, how do you think the reduction in energy consumption by humans can help slow climate change?



Figure 13.29 Vehicle in Singapore that runs on electricity

How Human Actions Can Reduce the Effects of Enhanced Global Warming

- Reduce the use of fossil fuel. Use renewable sources of energy like solar energy and wind.
- Reduce our consumption of energy. We can save electricity by using more efficient devices, e.g. use LED light bulbs.
- Replace petrol-powered vehicles with hybrid or electric vehicles.
- Reduce daily consumption of electricity, water, paper and plastic.
- Forest management:
 - Conservation of forest: Disruption of natural cycles such as the carbon cycle can be prevented, and this helps to prevent global warming.
 - Indiscriminate felling of trees should be prevented.
 - Reforestation: New seedlings can be planted to replace trees that have been removed or destroyed.
 - Control of forest fires: Some forest fires are man-made. People set fires to clear forests to provide land for agriculture. This must be prevented.
 - Education programmes should be conducted to make people aware of the importance of forests to our lives and the methods by which forests can be conserved.

The Singapore Green Plan 2030 is a nationwide movement to advance Singapore's national agenda on sustainable development. It aims to ensure that Singapore will remain a green and liveable home for current and future generations. Some of the key initiatives include:

- to reduce carbon emissions, keep our environment clean
- to save resources and energy
- to use cleaner energy and lower our carbon footprint



Link

Chemistry

We learn that the carbon cycle maintains the level of carbon dioxide in the atmosphere. Carbon dioxide and methane are the main greenhouse gases. Global warming is caused by the build-up of greenhouse gases in the atmosphere.



Now, look at Figure 13.30. Give your views on the statements made.

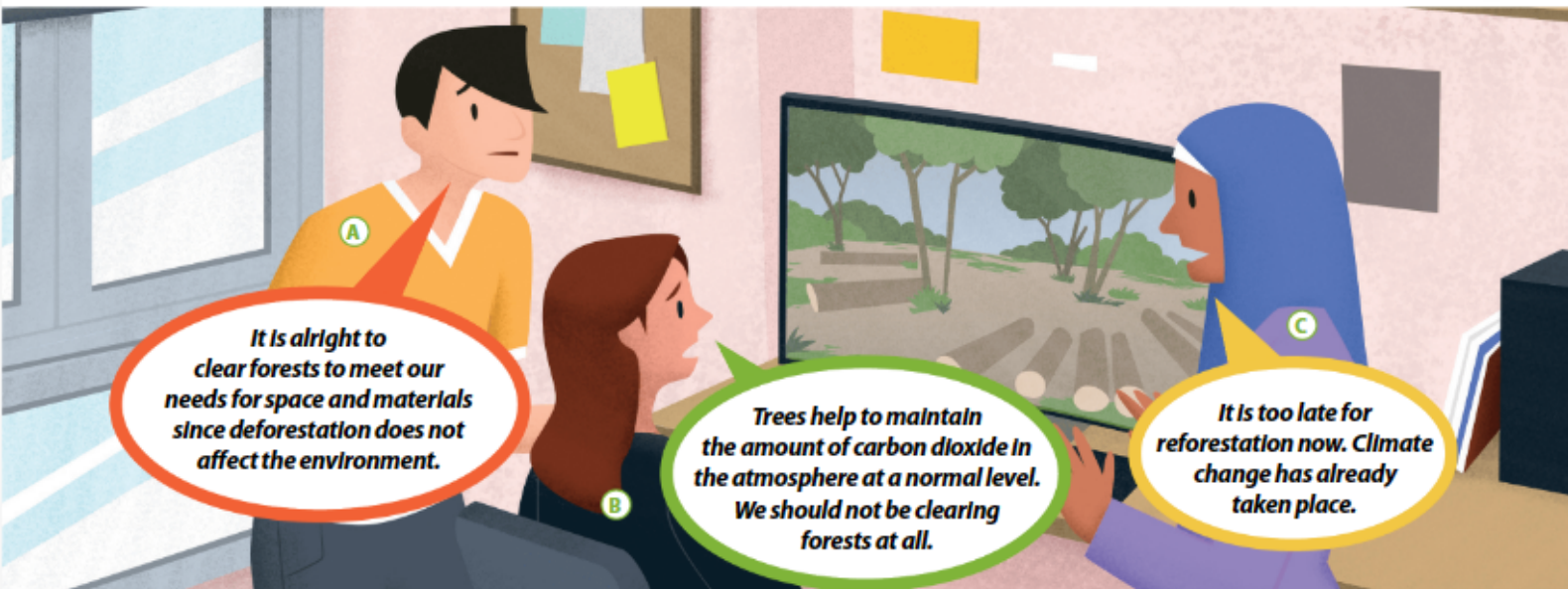


Figure 13.30 Three people are discussing deforestation and the environment. Do you agree? Why or why not?

Pollution

What Is Pollution?

Pollution is the process by which harmful substances are added to the environment, making it undesirable or unfit for life. Substances that cause pollution are called pollutants. Some causes of pollution are natural, for example, volcanic eruptions and forest fires. However, most pollution is the result of human activities.

Pollution has been a problem for humans for many years. As human population increases and technology advances, the problem of pollution becomes more serious. Pollution threatens the lives of organisms in the ecosystem. Therefore, the sources of pollution need to be identified and methods need to be devised to prevent and reduce pollution.

Waste materials dumped into water bodies, such as rivers, streams and lakes, pollute the water and change the communities that live in such habitats. Before 1977, many of the rivers in Singapore were so polluted that no fish could live in them (Figure 13.31(a)). Since then, the causes of water pollution have been identified, and tremendous efforts made to clean up the rivers (Figure 13.31(b)).

Figure 13.31
Singapore River,
in the past and
present

(a) Polluted Singapore River in the 1970s



(b) Clean Singapore River today





Link

Cholera outbreaks can kill many people if treatment is not administered. How can we prevent and control the spread of cholera? Look back at Chapter 11.

Let us look at some causes of water pollution and their effects.

Sewage

Water-carried waste matter from homes or industries is called **sewage**. Untreated sewage should not be discharged into rivers or lakes as it may contain disease-causing organisms such as bacteria. If these disease-causing organisms get into drinking water, they may infect a large number of people in the community with diseases. Cholera and typhoid are examples of water-borne diseases caused by bacteria.

Untreated sewage contains phosphates and nitrates. These are nutrients for algae and water plants. When untreated sewage enters water bodies, it can result in excessive growth of algae and water plants. This can promote bacterial growth. Other organisms in the water may die due to lack of oxygen. This can lead to *eutrophication*. Besides untreated sewage, eutrophication can also be caused by excessive amounts of inorganic chemical fertilisers entering water bodies.

Eutrophication is the process by which water receives excess nutrients like phosphates and nitrates, causing excessive growth of algae and water plants.

The process and effects of eutrophication are described in Figure 13.32.



Word Alert

Submerged: as an adjective, the word means under the surface of water

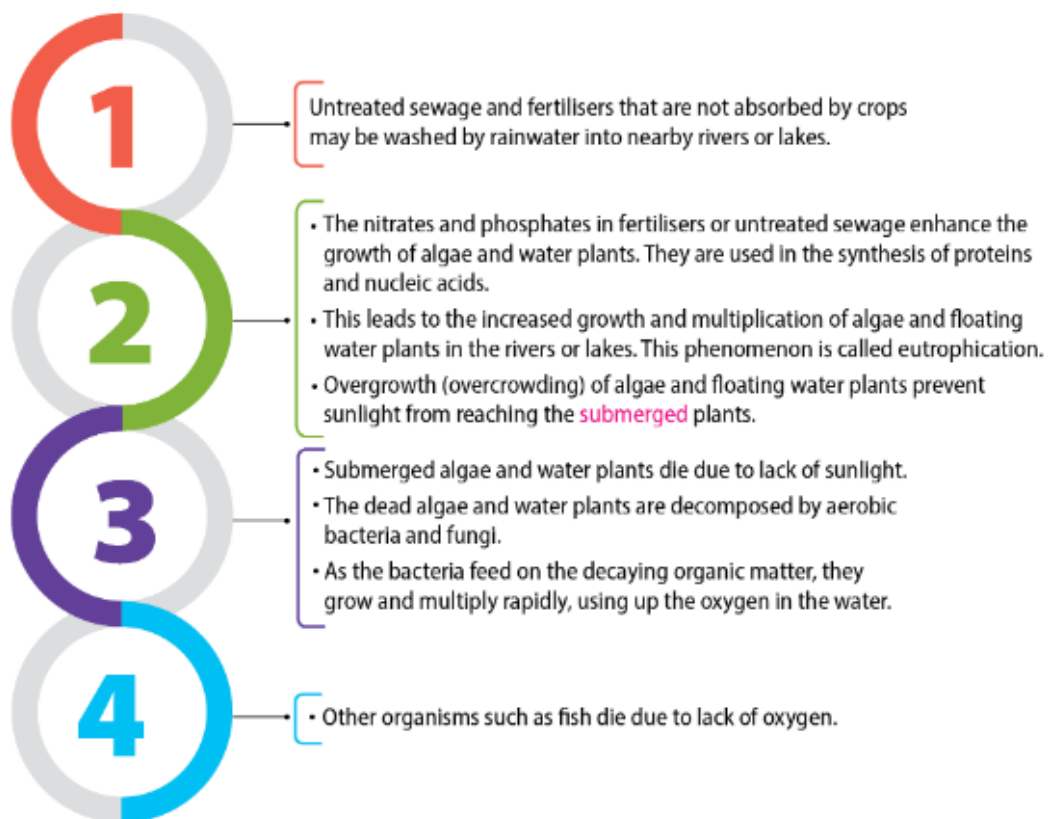


Figure 13.32 Process and effects of eutrophication

Insecticides

Insecticides are substances used to kill insects. These insects may:

- destroy crop plant
- transmit diseases, for example, dengue fever and malaria

One disadvantage of using insecticides is that the insecticides may become ineffective after some time. This is because some insects become resistant to the insecticides. They pass the favourable genes to their offspring and over time, the population of insects will rise again.

Another disadvantage is that the insecticides may end up affecting organisms other than insects. If insecticides are carried by rainwater into streams, rivers and lakes, they can accumulate in high concentrations in the bodies of aquatic organisms such as fish.

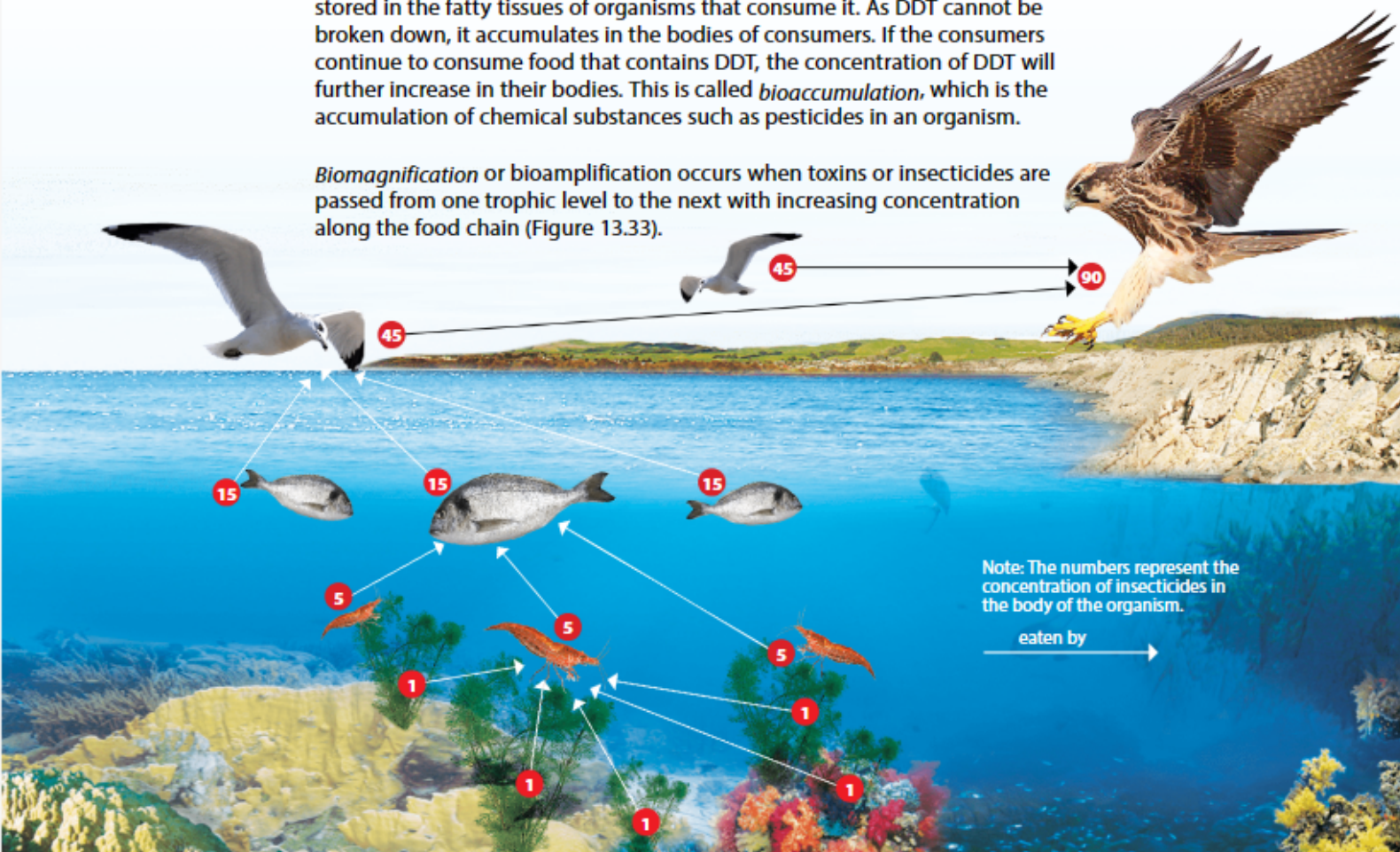
DDT (dichlorodiphenyltrichloroethane) is an insecticide that is non-biodegradable. This means that it cannot be broken down by micro-organisms like bacteria. It remains in the soil or water for many years. Since DDT is insoluble in water, it is not excreted. Instead, it is stored in the fatty tissues of organisms that consume it. As DDT cannot be broken down, it accumulates in the bodies of consumers. If the consumers continue to consume food that contains DDT, the concentration of DDT will further increase in their bodies. This is called *bioaccumulation*, which is the accumulation of chemical substances such as pesticides in an organism.

Biomagnification or bioamplification occurs when toxins or insecticides are passed from one trophic level to the next with increasing concentration along the food chain (Figure 13.33).



Link

How do insects become resistant to insecticides? Look ahead to natural selection in Chapter 18.



- **Biomagnification** occurs when certain chemicals, e.g. insecticides, are passed along the food chain, increasing in concentration in the bodies of organisms along the trophic levels.

Figure 13.33
Insecticide increases in concentration along a food chain.

The top consumers in a food chain can accumulate large amounts of DDT from eating affected prey. Due to biomagnification, top consumers with high concentrations of DDT in their bodies may suffer toxic effects. The events in Minamata, Japan, which led to people being poisoned by mercury are an example of biomagnification.

Effects of Non-biodegradable Plastic Waste on the Ecosystem

- Burning of plastic waste and its effect on global warming has already been discussed.
- Plastic waste deposited in landfills:
Harmful chemicals from plastic waste buried in landfills may be **leached** into the rivers and seas. They poison wildlife in the sea or rivers.
- Plastic waste created from disposables, such as shopping bags, straws, cutlery, plates, bottles and boxes may be harmful to marine animals when they are washed into the sea.
- Plastic waste can be broken down into tiny pieces of plastic, known as microplastics. These can be ingested by marine organisms and accumulate in their bodies. This leads to biomagnification of microplastics along the food chain.

Many animals die from feeding on plastic waste in the landfills or in the sea. Plastics are indigestible. Marine life such as turtles and dolphins die when



Word Alert

Leached: drained away



Figure 13.34 Turtles may mistake plastic bags as jellyfish and eat them.



Link

Theory Workbook
Worksheet 13D

Let's Practise 13.5

- 1 What is the difference between bioaccumulation and biomagnification?
- 2 What is the effect of plastic pollution?
- 3 What is eutrophication? How does discharge of raw sewage into nearby rivers cause eutrophication?



13.6 Why Is There a Need for Conservation?

Learning Outcome

- Discuss how the conservation of species and sustainable use of natural resources contribute to the maintenance of biodiversity and a balanced ecosystem (e.g. coral reef, tropical rainforest, mangrove).

We know that if we do not spend our allowance carefully, we will not have enough to last through till the next time we receive some. Wisdom tells us that it is good to spend less than what we receive or earn. This ensures that we are not short of money for emergencies. Conservation is similar — making sure we do not overuse and managing the natural resources, so that we do not cause lasting damage.

The Need for Conservation

No one knows for sure what the total number of species on Earth is. There may be 10 million or 100 million species! However, out of this vast number of species, barely two million have been identified and studied by scientists. Many organisms in aquatic habitats have not been discovered or intensively studied due to human and technological limitations. Tropical rainforests have the most diverse ecosystem in the world (Figure 13.35).



Sadly, many species, are becoming extinct even before they can be discovered or studied. As you have learnt, human activities can upset the balance of nature, often with disastrous results. We have depleted many of our precious natural resources, such as forests and fish. Pollution caused by our activities also harms many organisms and destroys habitats. As a result, the rich **biodiversity** on Earth is being threatened. **Conservation** is necessary to maintain Earth's biodiversity.

- ▶ **Biodiversity** refers to the range of species that are present in a particular ecosystem.
- ▶ **Conservation** is the protection and preservation of natural resources in the environment.



Cool Career

Nature conservation officer

Do you have a keen interest in protecting the environment? Do you enjoy working outdoors? The main responsibilities of a nature conservation officer involve planning and implementing schemes aimed at preserving and protecting areas of natural beauty, and promoting biodiversity. These officers also increase the awareness of conservation in the community by educating the public.

Figure 13.35 The Amazon rainforest is home to thousands of plant and animal species, and millions of different insects.

Figure 13.36 explains why conservation programmes may be necessary.



Figure 13.36 Reasons for conservation and conservation programmes

How Can Resources Be Conserved and Managed Sustainably?

The forest, mangrove swamp and coral reefs are balanced ecosystems. They are carbon sinks and rich in biodiversity. Conservation measures and lifestyle changes are needed to maintain such a rich diversity of life.

Conservation of Forests

Forest conservation has already been discussed.

Conservation of Mangrove Swamps

Some countries have a Mangrove Restoration Project. Volunteers plant mangrove seedlings over a portion of the mangrove swamp. The trees that develop will protect low-lying areas against strong wind, waves and tides (Figure 13.37).

Adopt a Mangrove Programme is a campaign initiated at Pulau Ubin to raise awareness about conservation and restoration of degraded areas to reduce the impact of global warming and climate change.

Figure 13.37 Mangrove swamp in Pulau Ubin



Conservation of Coral Reefs

Beautiful corals can be found in places such as the Great Barrier Reef in Australia (Figure 13.38). People visiting coral reefs should practise safe and responsible diving. Divers should not touch the reefs as they may damage the coral animals. Divers should not anchor their boats on the reef as they may kill the corals.

Some guidelines for visitors to the reefs should be followed:

- Avoid using sunscreen as some ingredients in sunscreen can be harmful to corals.
- Avoid purchasing living corals as this will encourage people to extract live corals for sale.
- Avoid polluting the coastline with trash, especially non-biodegradable plastic. Such marine debris may be blown or washed away into the ocean. They can be harmful to coral reefs.

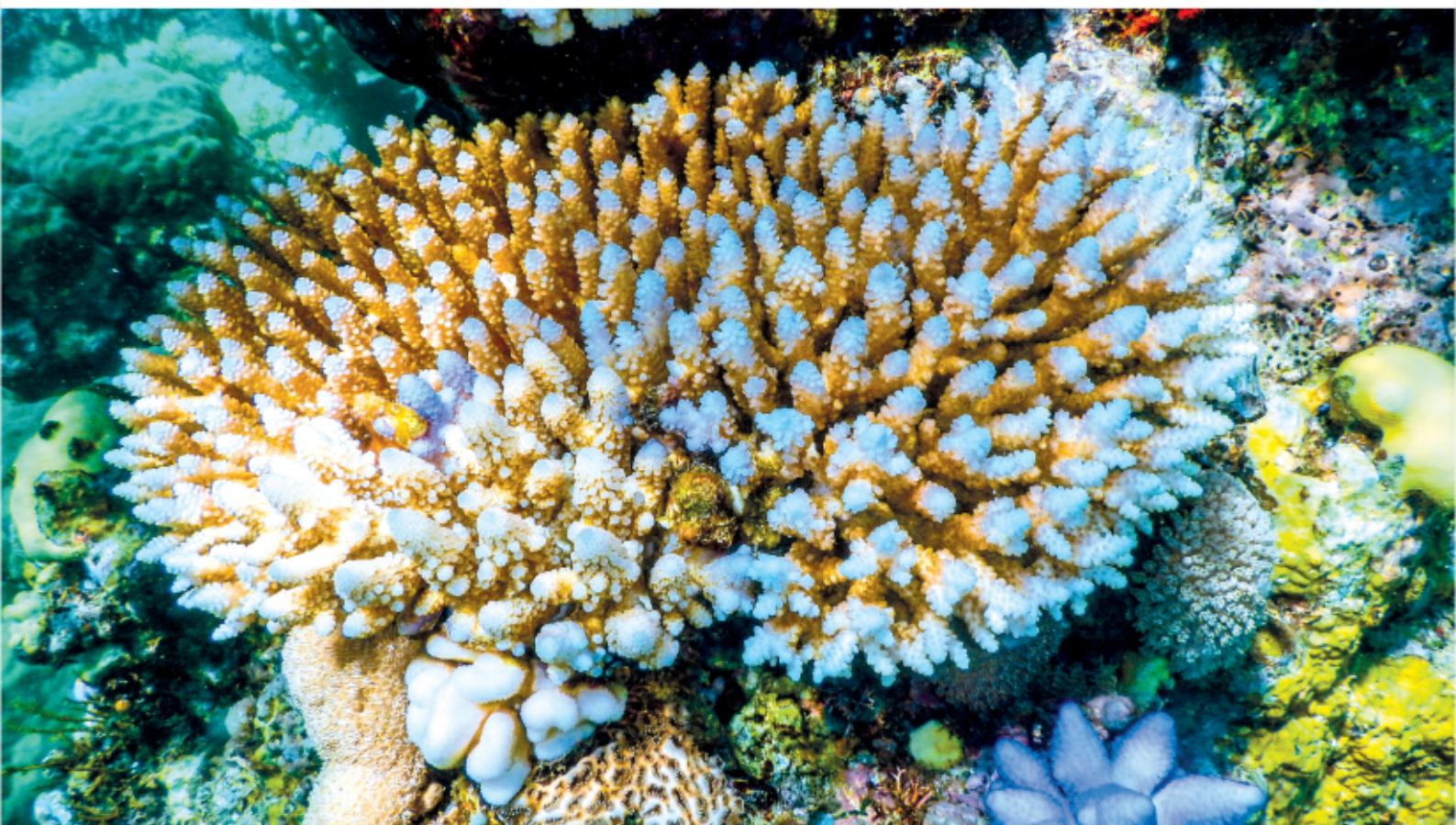


Figure 13.38 Corals provide a home to about 25% of all the world's marine life.



Link

Theory Workbook
Worksheet 13E
Let's Assess
Let's Reflect

Let's Practise 13.6

- 1 Why is it important to maintain biodiversity?
- 2 How will controlling the human population size help in conservation?



Problem-based Learning Activity

Research that spans many decades has provided evidence that the rising carbon dioxide level in the atmosphere is one of the main factors that cause the Earth's temperature to rise.

Rising temperatures have a potentially catastrophic effect, as it would result in the melting of the ice glaciers in the North and South Poles (Figure 13.39). This will increase the sea levels around the world, potentially resulting in coastal cities and island countries sinking in the foreseeable future. Imagine this happening to us in Singapore! Singapore will be considering a range of options, including reclamation and building sea walls, as well as nature-based solutions, to protect against rising levels.



Link

Theory Workbook
Problem-based Learning:
Application



Figure 13.39 Splinters of ice peel off from the glacier.

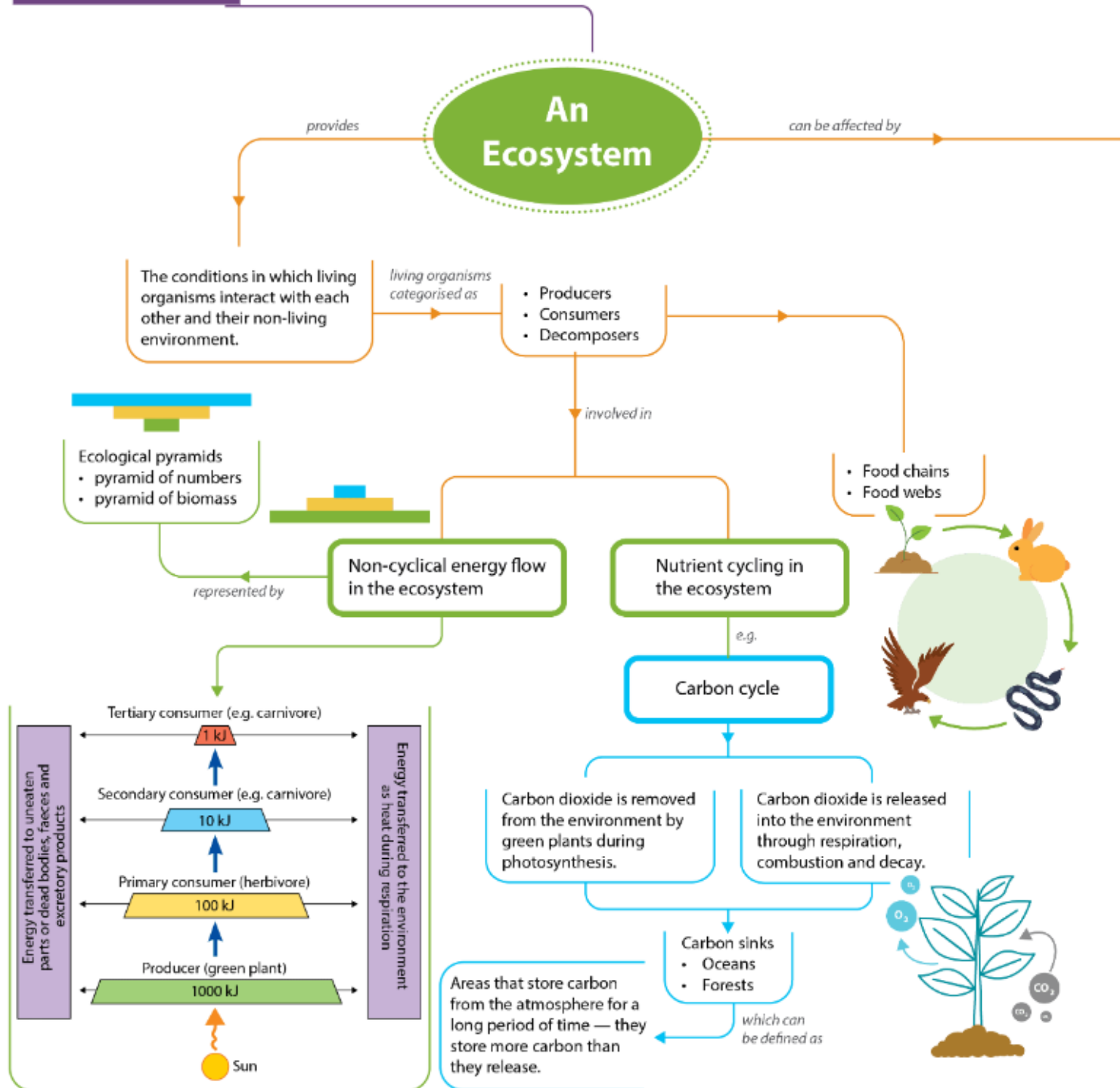
You have learnt that plants absorb carbon dioxide and produce food substances, such as glucose, during photosynthesis. Plants, such as trees in forests, are therefore capable of slowing down the rise of the carbon dioxide level in the atmosphere.

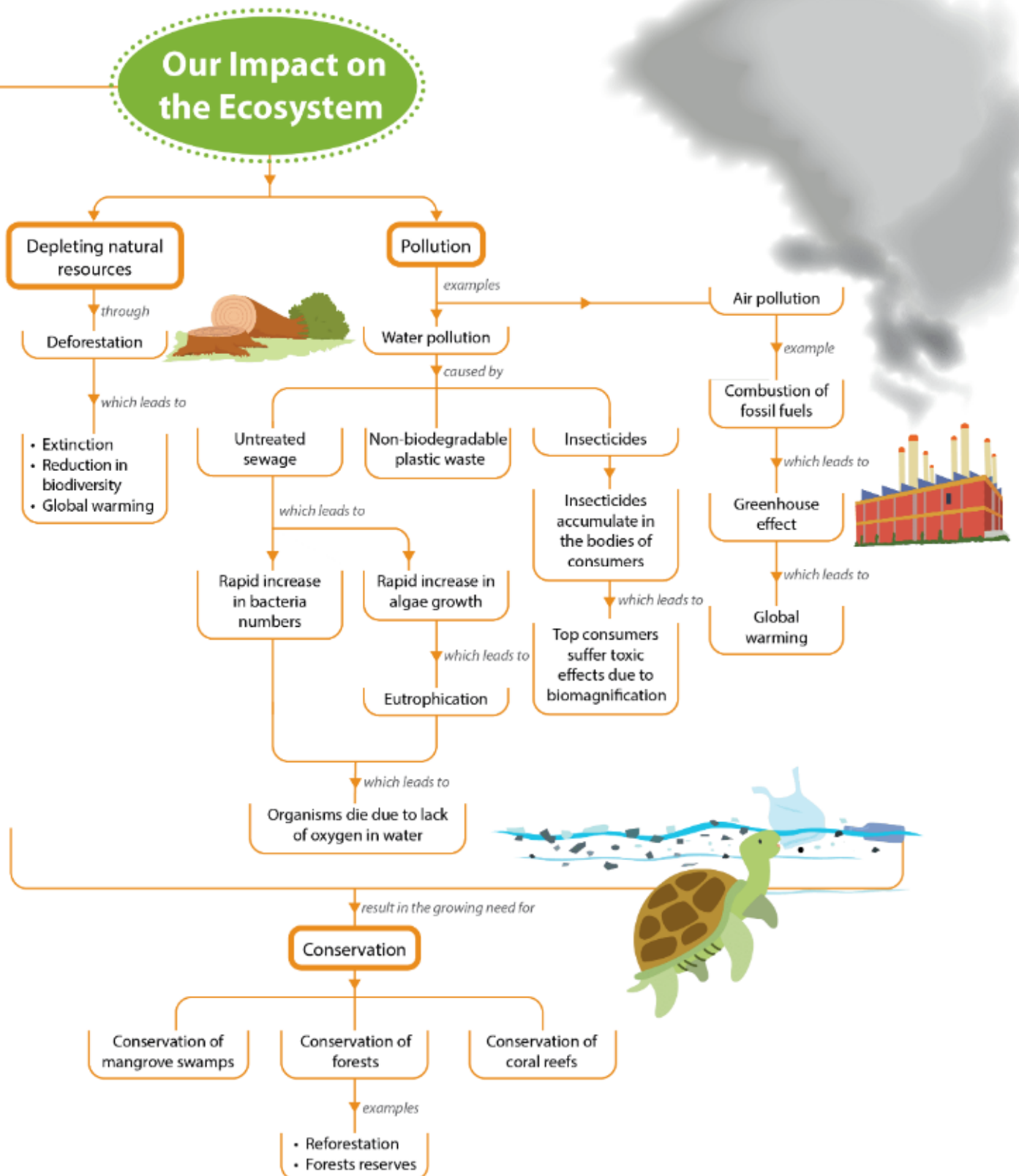
However, we also know that plants are used as raw materials for building houses, making furniture and utensils. For these uses, we need to cut down plants.

Consider the following questions:

- How do you think we can balance the use of plants as regulators of carbon dioxide level in the atmosphere, and the use of plants for other purposes?
- Balancing the use of plants for different purposes would mean making changes to our lifestyles. What should our attitude be and how should we live our lives if we are committed to preventing the carbon dioxide level from rising any further?
- In Singapore, the Singapore Green Plan 2030 is one of many government initiatives aimed at reducing the carbon dioxide level in the atmosphere. What other initiatives are in place? Is Singapore doing enough to control the amount of carbon dioxide released into the environment?

Let's Map It





Let's Review

Section A: Multiple-choice Questions

- 1 Figure 13.40 shows a food web associated with a mango tree.

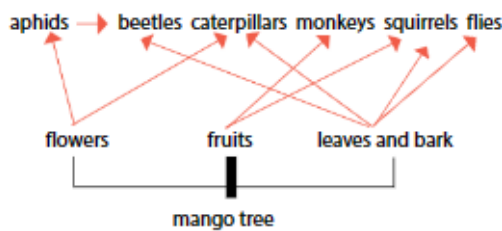


Figure 13.40

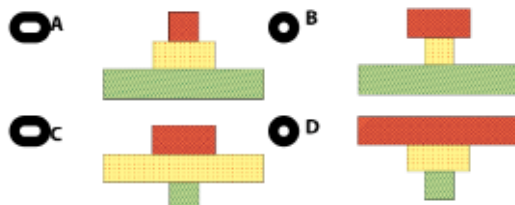
Which animal would be most affected if pollination of the mango tree flowers did not take place?

- ☐ A beetles ☐ B caterpillars
☐ C flies ☐ D squirrel

- 2 When you eat a carnivorous fish, you are a _____.

- ☐ A decomposer
☐ B primary consumer
☐ C secondary consumer
☐ D tertiary consumer

- 3 The size of each trophic level in the diagrams below represents the number of producers, primary consumers or secondary consumers in a particular food chain. Which diagram shows the pyramid of numbers for the following food chain:
 grass plants → rabbits → parasitic fleas?



Key:
■ Producers ■ Primary consumers ■ Secondary consumers

- 4 The graph in Figure 13.41 shows the oxygen concentration at five different stations, each located 100 m from each other, downstream of a river. Sewage was emptied into the river just after station A.

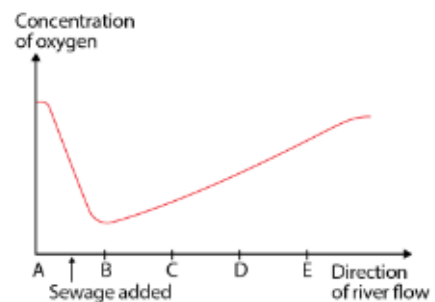


Figure 13.41

At which stations are the concentrations of organic matter the lowest?

- ☐ A stations A and E
☐ B stations B and C
☐ C stations C and D
☐ D stations D and E

- 5 Which of the following properties would ensure that an insecticide is less harmful to the environment?

- ☐ A It is easily broken down by bacteria in the soil.
☐ B It is easily washed into nearby lakes and rivers.
☐ C It is stored in the bodies of consumers.
☐ D It is readily absorbed by plant roots.

- 6 Lichens are bioindicators for air pollution. They are especially sensitive to sulfur dioxide, a harmful pollutant that is released when fossil fuels are burnt. The graph in Figure 13.42 shows how the number of lichens growing in an area varies with the area's distance from a coal-fired power station.

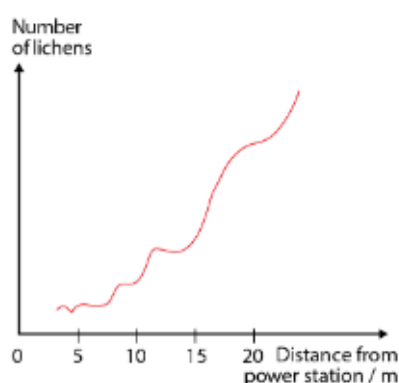


Figure 13.42



Which of the following is the best conclusion that can be drawn from the graph?

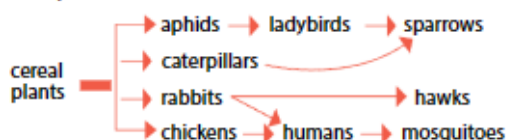
- ☐ A Fewer lichens grow near the power station.
- ☐ B Lichens reproduce at a constant rate near the power station.
- ☐ C Many lichens are killed far away from the power station.
- ☐ D There are more lichens growing near the power station.

Section B: Structured Questions

- 1 (a) Name the process by which energy enters an ecosystem.
(b) How does a producer differ from a consumer?
- 2 Consider the following food chains:
(a) grass plants → rabbits → snakes → hawks
(b) oak tree → insects → small birds → owls

For each food chain, draw a diagram to represent the pyramid of biomass and another diagram to represent the pyramid of numbers.

- 3 Study the food web and answer the questions.



- (a) Name the secondary consumers in the food web.
- (b) Why is the cereal plant known as a producer?
- (c) Draw a pyramid of numbers for the food chain shown below:

cereal plants → chickens → humans → mosquitoes

- 4 Pyrethrum, a natural product from chrysanthemum flowers, is an example of a biodegradable insecticide. Biodegradable insecticides can be broken down in the environment. However, pyrethrum is also toxic to fish. What advice would you give to a person using this insecticide in his or her garden and why?

- 5 Using insecticides can affect an ecosystem. The data in Table 13.4 are for an ecosystem near a shore, Long Island Sound, which was sprayed with DDT to control fly populations. Phytoplankton, tiny photosynthetic organisms that float on the surface of the sea, are the producers in this ecosystem. Small animals called zooplankton feed on the phytoplankton. The concentration of DDT is measured in **parts per million** or **ppm**. This means that if there were 1 molecule of DDT to 1 million molecules of water, the concentration of DDT would be 1 ppm.

Table 13.4

Component of the Ecosystem	Concentration of DDT / ppm
Phytoplankton	0.000003
Zooplankton	0.04
Small fish (minnows)	0.5
Large fish (needlefish)	2.0
Fish-eating birds (ospreys)	20.0

- (a) Using the information given, write the most likely food chain for the ecosystem.
- (b) Calculate the increase in the concentration of DDT at each trophic level in the food chain. This increase is called *biomagnification*. At which trophic level does the largest magnification take place?
- (c) The ospreys were not killed by this level of DDT in their bodies. However, they began to lay eggs with increasingly thin and brittle shells. How would this affect the population size of the ospreys? What effect might this have on this ecosystem?
- (d) Rather than measuring the concentration of chemicals in the environment, biologists often observe the changes in the numbers or health of organisms to study the effects of pollution in an ecosystem. Can you suggest why?

Section C: Free-response Questions

- 1 How is carbon cycled within an ecosystem?
Your answer should include the following terms: *respiration*, *combustion*, *photosynthesis* and *decomposition*.

- 2 In a pond, fluctuations in the populations of producers and primary consumers were measured over a period of two years. The results are shown in the graph in Figure 13.43.

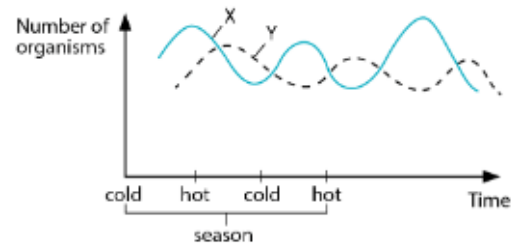


Figure 13.43

Which of the curves X and Y represent the primary consumer and producer respectively? Give reasons for your answer.

- 3 (a) Define what a carbon sink is and state **two** examples.
(b) What is the role of carbon sinks in global warming?
- 4 Discuss the effects of deforestation on the ecosystem.
- 5 Discuss the effects of the dumping of untreated sewage into rivers.
- 6 Discuss the importance of the conservation of species to humans.

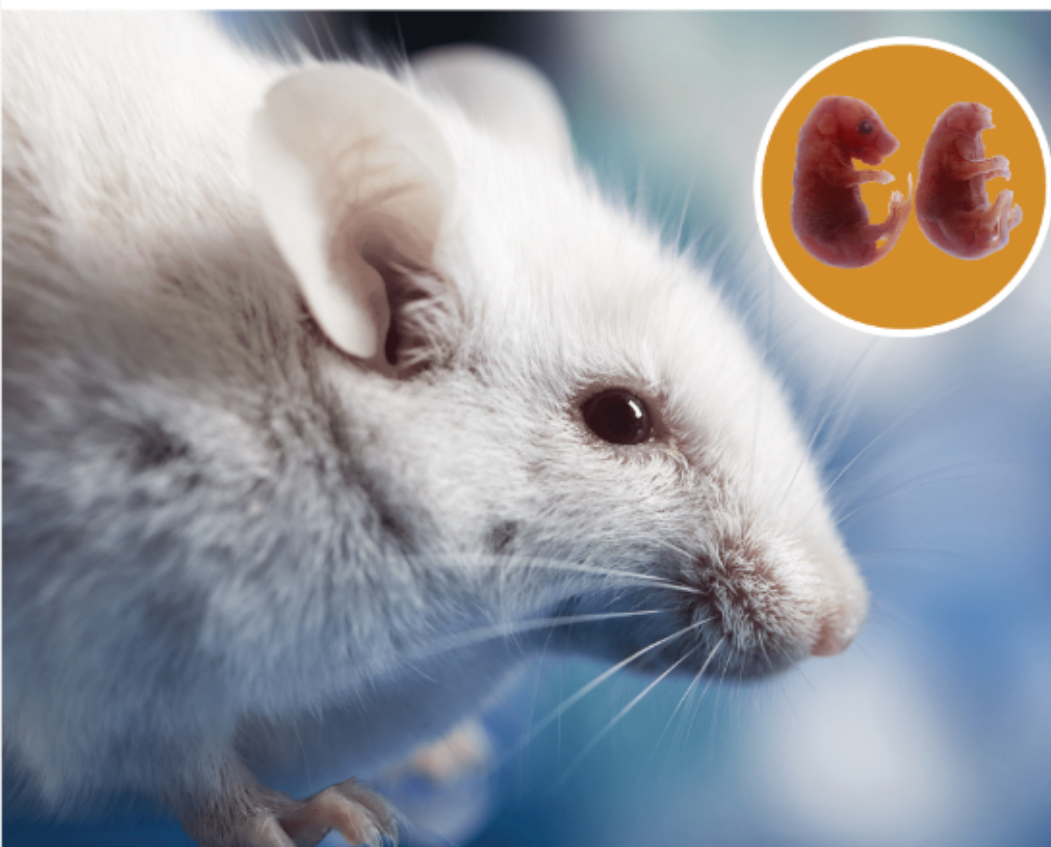


Link

Theory Workbook
Revision Worksheet 3

CHAPTER

14 Molecular Genetics



What You Will Learn



- What is DNA?
- What are genes?
- How can genes be transferred between organisms?
- What are the considerations surrounding genetic engineering?

A group of scientists experimented on laboratory mice to investigate the importance of proteins in the animal system. They were particularly interested in one protein molecule. Let us call this molecule, protein X. They experimented in such a way that the mice that were developing in their mothers' wombs did not produce protein X. All other proteins in the bodies of the mice were not affected. As a result, these mice were born headless. The other parts of their bodies developed normally.



How did the group of scientists stop the mice from producing protein X? Are the results of these experiments good or bad news for mankind? Some people think that this research is inhumane and condemn it while others saw it as a beneficial and important breakthrough in genetic engineering. Which viewpoint do you agree with?

14.1 What Is DNA?

Learning Outcomes

- Outline the relationships among DNA, genes and chromosomes.
- State that DNA is a double helix comprising two strands of nucleotides, each nucleotide formed of a sugar, a phosphate group and one of four different bases.
- State the rule of complementary base pairing.

Before a building is constructed, there has to be a blueprint that details how the building will look like. Your body is much more complex than a building, but can you imagine that a complete blueprint and plan is contained within every single cell of your body?

Deoxyribonucleic acid or **DNA** is a molecule that carries genetic information. The information carried by DNA is important for all cellular functions, such as cell division and cell differentiation. Cells would not be able to carry out these vital functions without DNA. Thus, almost all the cells in your body contain DNA inside their nuclei. About two metres of DNA can be found in each cell nucleus!

How Is DNA Organised Inside Cells?

Figure 14.1 shows the structure of DNA.

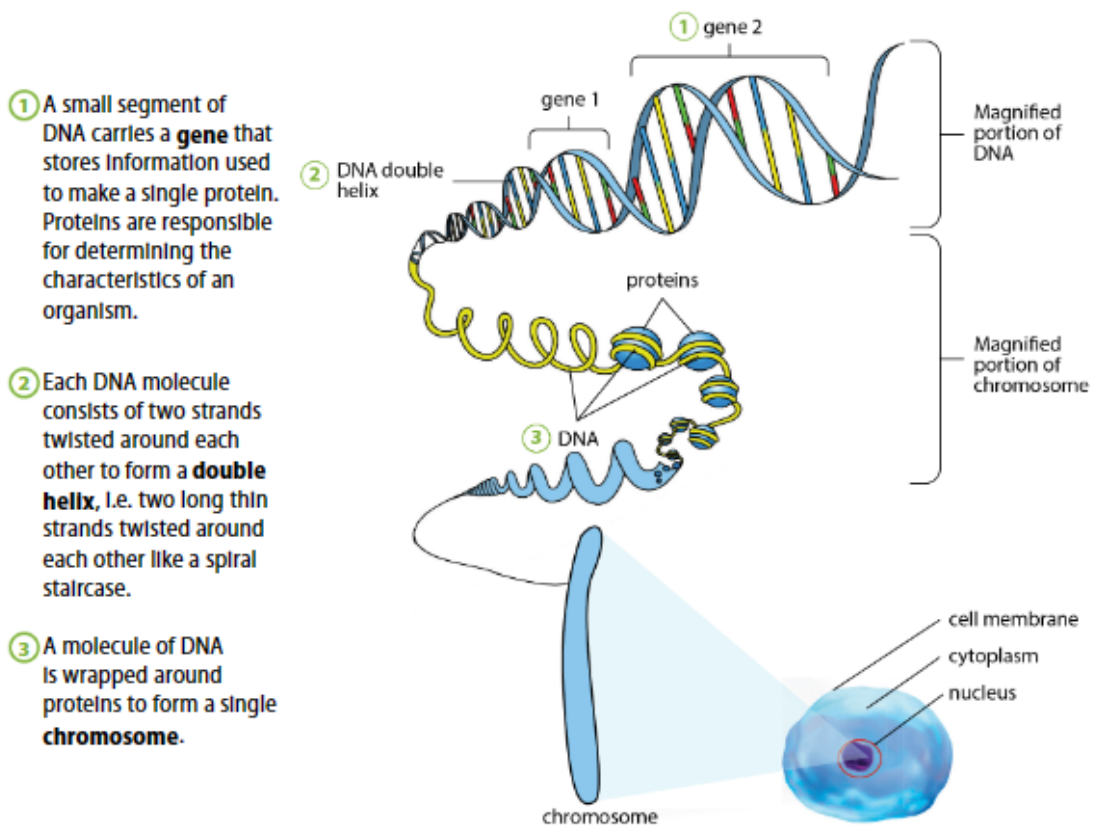


Figure 14.1 How DNA is packaged inside a cell nucleus

DNA can be extracted from the nucleus of cells. In its purified form, it appears as very fine white threads (Figure 14.2).

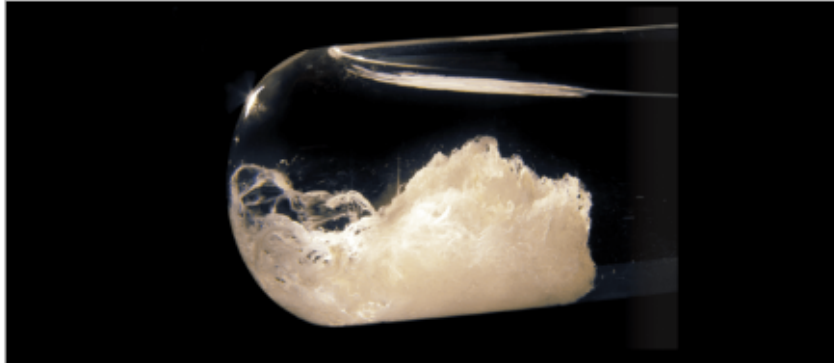


Figure 14.2 Isolated DNA in a test-tube



Disciplinary Idea Structure and Function

The structure of the DNA molecule enables it to store information needed to make proteins that carry out vital functions in an organism.

How Are Chromosomes, DNA and Genes Related?

From Figure 14.1, you have seen that a chromosome consists of a DNA molecule coiled around proteins. You have also seen that DNA consists of segments of genes that store information. To understand how information is stored in DNA, you first need to know the basic units that make up its structure.

Basic Units of DNA

The basic unit of DNA is called a **nucleotide**. Each nucleotide is made up of the following:

- a sugar
- a **phosphate group**
- a nitrogenous **base**

There are four different nitrogenous bases in DNA. The bases are called **adenine** (A), **cytosine** (C), **guanine** (G) and **thymine** (T). These may be represented by the symbols shown in Figure 14.3.



Figure 14.3 Building blocks of nucleotides



Helpful Note

The sugar in the DNA nucleotide is called deoxyribose.

Putting Nucleotides Together

The sugar, phosphate group and one of the four bases can combine to form a nucleotide as shown in Figure 14.4.



Figure 14.4 Nucleotides

Nucleotides can be joined together to form long chains called **polynucleotides** (Figure 14.5).

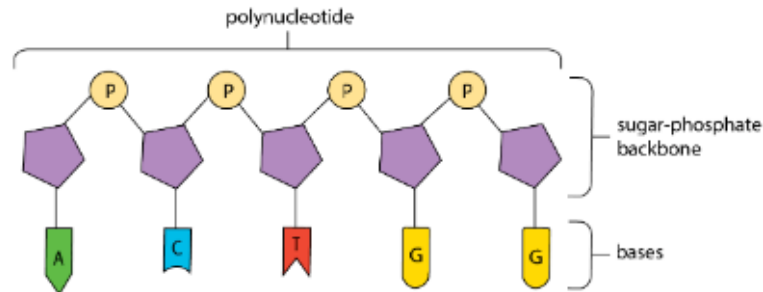


Figure 14.5 Polynucleotide

Each gene is made up of a sequence of nucleotides. The sequence of nucleotides (bases) can vary. This results in many different genes.

Rule of Base Pairing

The DNA molecule is made up of two polynucleotide chains. The sugar-phosphate backbone is found on the outside of the DNA molecule, while the bases are found on the inside of the DNA molecule. The bases of one chain are bonded to those of the opposite chain according to the **rule of base pairing**. How does the rule work (Figure 14.6)?

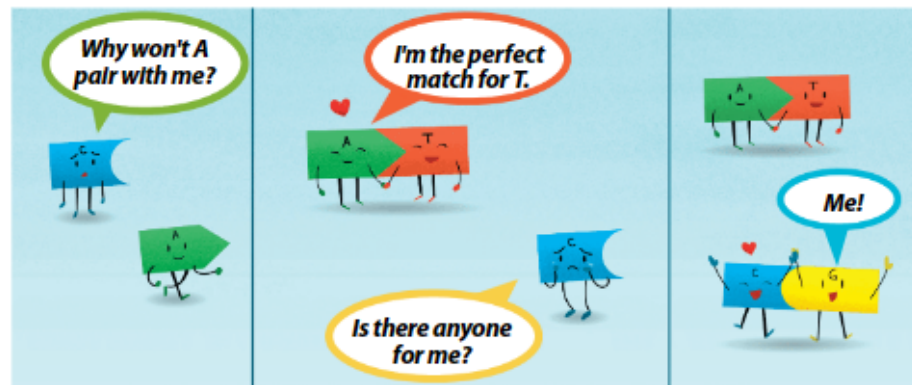


Figure 14.6 Base pairing in the DNA molecule is very specific.



Link

Physics

Ionising radiation such as X-rays and gamma rays are part of the electromagnetic spectrum. Over-exposure to such radiation can have harmful effects on living cells and tissues. For example, it can damage the DNA structure by breaking the hydrogen bonds or causing damage to the bases.

Adenine (A) is bonded to thymine (T) and cytosine (C) to guanine (G). This is called **complementary base pairing** because A has a shape complementary to that of T and C has a shape complementary to that of G. Complementary bases are held by hydrogen bonds (Figure 14.7).

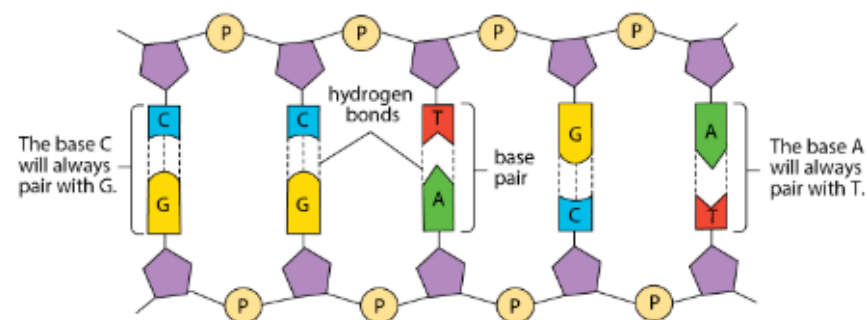


Figure 14.7 Complementary base pairing

In a DNA molecule, the ratios of adenine to thymine (A:T) and cytosine to guanine (C:G) are always 1:1.

Worked Example 14A

If adenine forms 35% of the nitrogenous bases in a particular DNA molecule, what percentage of the bases would be guanine?

Solution

According to the rule of base pairing, adenine (A) always bonds with thymine (T), while cytosine (C) always bonds with guanine (G).

The ratios of A:T and C:G are 1:1.

$$\begin{aligned}\text{Percentage of T + A} &= 35\% + 35\% \\ &= 70\%\end{aligned}$$

$$\begin{aligned}\text{Percentage of C + G} &= 100\% - 70\% \\ &= 30\%\end{aligned}$$

$$\begin{aligned}\text{Hence, percentage of G} &= \frac{30\%}{2} \\ &= 15\%\end{aligned}$$



Link

Practical Workbook
Experiment 14A

An uncoiled DNA molecule can be represented by the simple model as shown in Figure 14.8. An uncoiled DNA molecule resembles a ladder. The twists of the coiled DNA molecule resemble a spiral staircase or double helix.

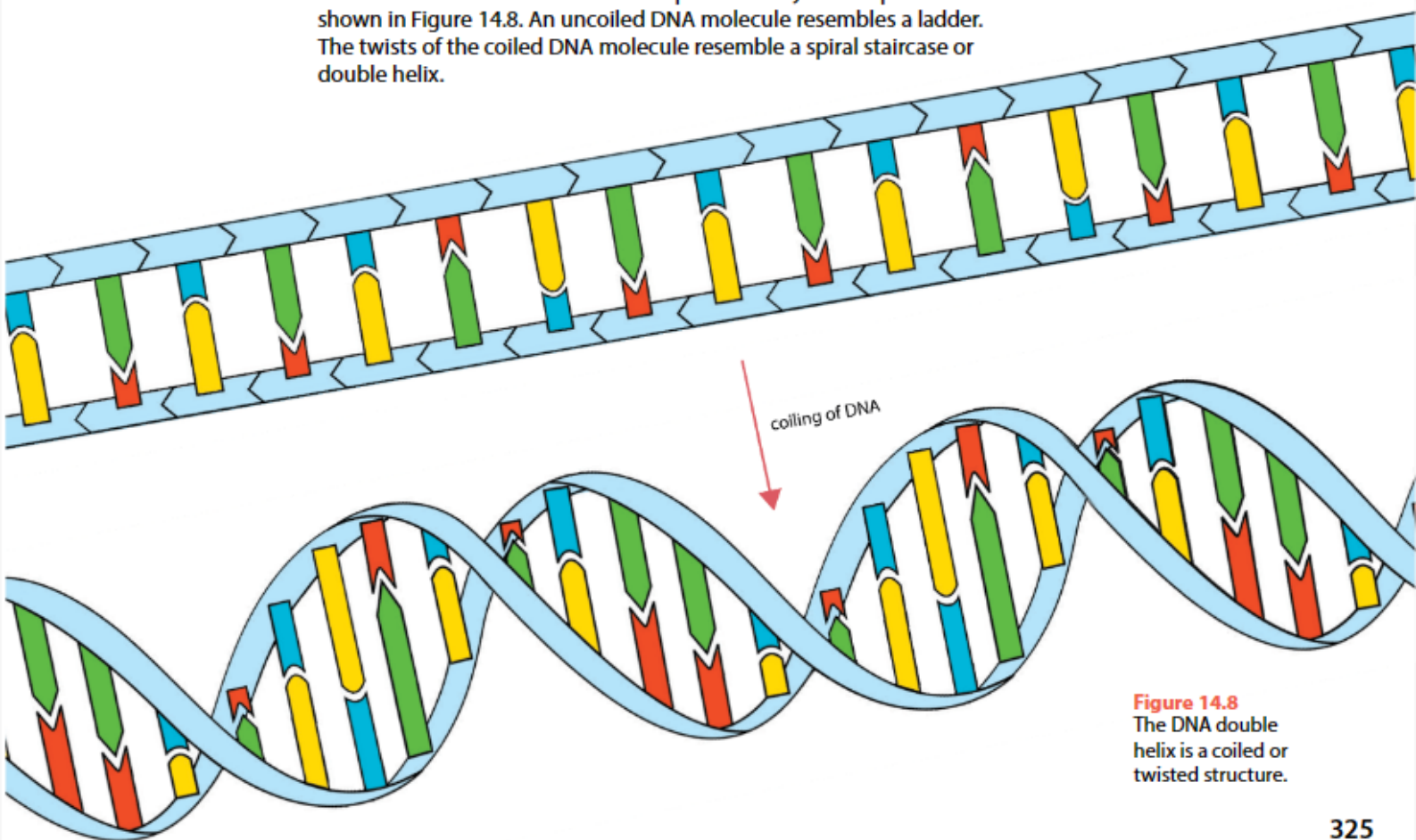


Figure 14.8
The DNA double helix is a coiled or twisted structure.



Past to Present

James Watson and Francis Crick first discovered the double helix structure of DNA in 1953. This discovery resulted from the effort in analysing, making linkages and further developing information about DNA that was obtained by other scientists. They were awarded the Nobel Prize in Physiology or Medicine in 1962 for this important discovery. Do you think they would have made this discovery without looking into the previous works done by other scientists, such as Rosalind Franklin's work to establish the DNA molecule to exist in a helical form? Why?

Watson and Crick's research article entitled *A Structure for Deoxyribose Nucleic Acid* in the scientific journal *Nature* has paved the way for many great advancements in genetic engineering that we see today.



Figure 14.9 James Watson and Francis Crick won the Nobel Prize for their discovery of DNA's double helix.



Link

Theory Workbook
Worksheet 14A

Let's Practise 14.1

- 1 Can you describe the relationships among a gene, DNA and a chromosome?
- 2 The DNA structure is a double helix. What is meant by this?
- 3 If cytosine forms 40% of the nitrogenous bases in the DNA molecule, what percentage of the bases would be adenine?

14.2 What Are Genes?

Learning Outcomes

- State that each gene:
 - is a sequence of nucleotides, as part of a DNA molecule
 - codes for one polypeptide
 - is a unit of inheritance
- State that DNA is used to carry the genetic code, which is used to synthesise specific polypeptides.

When you try to cook a new dish, you will often need to refer to a recipe and follow the exact steps to produce the desired outcome. Genes are the recipe or instructions that tell your cells what to do. Just as different recipes give different results, different genes produce different traits.

A DNA molecule may carry many genes along its length. Genes are the *basic units of inheritance* in a living organism. A **gene** is a *sequence of DNA nucleotides (bases) that controls the formation of a single polypeptide*. A polypeptide can be used to make proteins. Each gene stores a message that determines how a protein should be made in a cell. The message stored by a gene is known as the **genetic code**.

The proteins contribute to the development of many characteristics in your body. If the message stored by a gene (sequence of nucleotides or bases) is altered, it may affect your body structure or function.



Disciplinary Idea

Heredity

Each DNA molecule carries many genes, each a unit of inheritance. The expression of genes results in the production of proteins that determine the traits of living organisms.



How Is a Polypeptide or Protein Made?

Figure 14.10 shows how the message from a gene, which is a small segment in the DNA molecule, is used to produce a polypeptide.

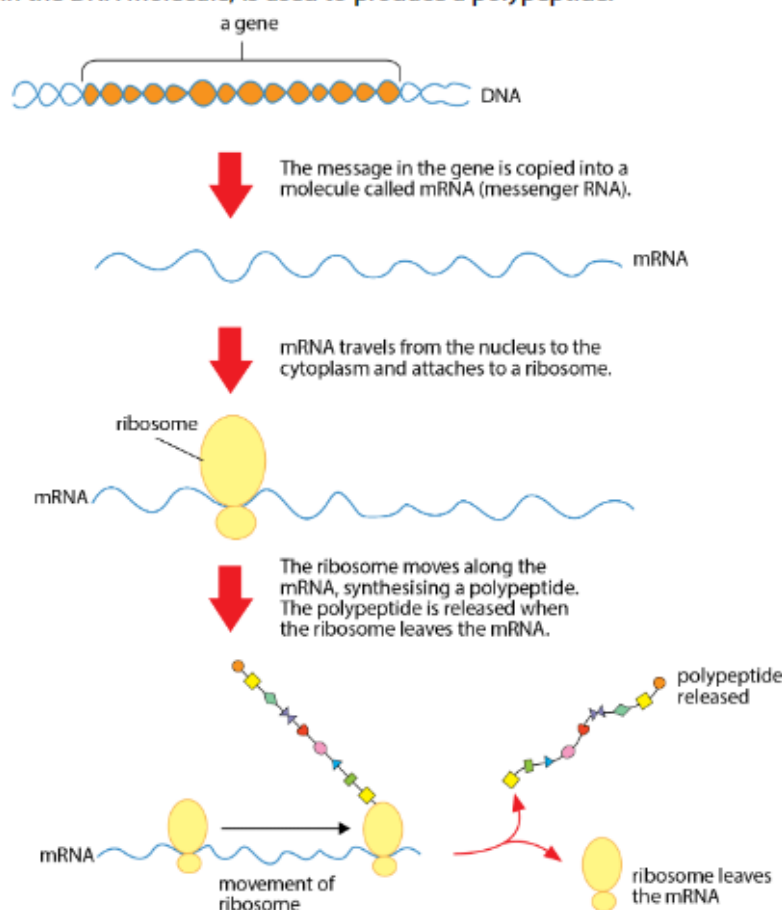


Figure 14.10 Production of a polypeptide

What determines the sequence or order of amino acids in the polypeptide or protein? There are four bases A, C, G and T in the DNA molecule. Three bases together make up a codon. Each codon codes for one acid. For example,

Codon:	CAA	CGG	CCA	TTT
	↓	↓	↓	↓
Amino acid coded for:	glutamine	arginine	proline	phenylalanine

Suppose the DNA strand that determines the production of the polypeptide or protein has the following sequence of codons: **CGG CCA CAA TTT**

The sequence of amino acids in the protein will be:

arginine – proline – glutamine – phenylalanine

However, if the sequence of codons is: **CCA CGG TTT CAA**

The sequence of amino acids will be:

proline – arginine – phenylalanine – glutamine

Hence, the sequence of bases in the DNA determines the sequence of amino acids in a polypeptide.



Link

Theory Workbook
Worksheet 14B

Let's Practise 14.2

- 1 Which of these four structures is part of the other three?

A chromosome	B white blood cell
C gene	D nucleus
- 2 Which of the following defines a gene?

A the sequence of nucleotides found in a polypeptide
B the sequence of nucleotides found in the DNA that codes for a polypeptide
C the sequence of amino acids found in the DNA that codes for a polypeptide
D the sequence of amino acids found in the polypeptide

14.3 How Can Genes Be Transferred Between Organisms?

Learning Outcomes

- State that genes may be transferred from the cells of one organism to the cells of another to form transgenic organisms.
- Briefly explain how a gene that controls the production of human insulin can be inserted into bacterial DNA to produce human insulin in medical biotechnology.

The genetic code of each species of organisms enables the species to survive and play its unique role on this Earth. Interfering with genetic codes may disrupt this balance. However, there can be some benefits. If we must delve into this risky business, we must do so with great care and precaution.

What Is Genetic Engineering?

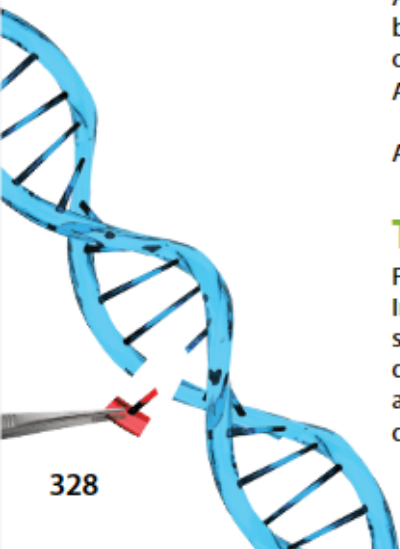
Genetic engineering is a technique used to transfer genes from one organism to another. Individual genes may be cut off from the cells of one organism and inserted into the cells of another organism of the same or different species. The transferred gene can express itself in the recipient organism.

A **vector** is required for the transfer of genes. A vector can be another DNA molecule, a bacterium or a virus that is used to carry the genes of one organism into another. Small circular DNA called **plasmids**, obtained from bacteria, can be used to transfer genes. A plasmid is an example of a vector.

A **gene-of-interest** is any gene that we want to transfer from one organism to another.

Transferring the Human Insulin Gene into Bacteria

People suffering from diabetes usually cannot control the amount of sugar in their blood. Insulin is needed to treat such patients. Insulin used to be obtained from the pancreas of slaughtered animals. However, animal insulin is not the same as human insulin. Many diabetics develop antibodies against animal insulin after prolonged treatment. Such patients become allergic to animal insulin and can no longer use animal insulin to control their diabetes. Also, diseases may be transmitted from animals to humans who use animal insulin.



Insulin produced by genetic engineering is exactly the same as ordinary human insulin. The advantages of producing insulin via this method are listed below:

- It does not induce an allergic response in the patient as the insulin produced is identical to human insulin.
- It is easier and cheaper to produce insulin in large quantities.
- There is less risk of contamination by disease-causing microorganisms like bacteria as compared to insulin obtained from the pancreases of animals.
- The ethical concerns of vegetarians or religious groups can be overcome. For example, vegetarians will object to the use of insulin obtained from animals.

Genes can be transferred from human cells to bacterial cells. This enables us to transfer the gene-of-interest, which makes human insulin, to bacterial cells. The bacteria acquire a foreign gene. The foreign gene causes the bacteria to produce insulin, a substance which is not normally produced by bacteria. An organism that has a foreign gene inserted into its **genome** or DNA is called a **transgenic organism**. In this case, the bacterium which acquires the human insulin gene, is a transgenic bacterium (Figure 14.11).

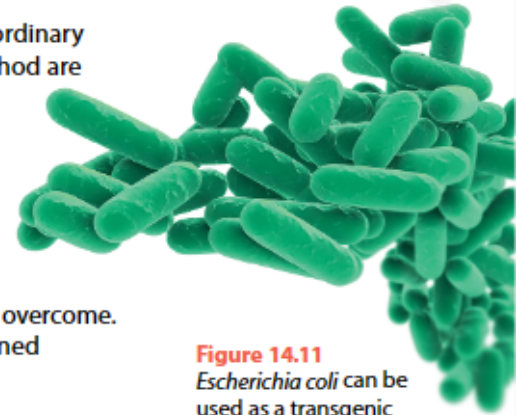


Figure 14.11
Escherichia coli can be used as a transgenic bacterium to produce human insulin.



Disciplinary Idea

Heredity

Genetic engineering allows for genes to be transferred between cells from organisms of the same species or different species. These genes can be passed down to the next generation. This results in the formation of transgenic plants or animals.



Word Alert

Genome: all of an organism's genetic information

Recombinant: joined together from different parts

Restriction Enzyme and Sticky Ends

To understand how a gene-of-interest can be transferred from one organism to another, we need to know what enzymes are involved and how these enzymes work (Figure 14.12).

- 1 A gene is a segment in the DNA molecule. On each side of the gene is a segment called the **restriction site**.
- 2 An enzyme called **restriction enzyme** can recognise and cut the restriction site to produce **sticky ends**.
- 3 DNA strands from two different organisms are cut by the same restriction enzyme to produce complementary sticky ends.
- 4 DNA fragments from two different sources are mixed together with an enzyme called **DNA ligase**.
- 5 The two different DNA fragments will bind together by complementary base pairing. They are then sealed together by the DNA ligase to form **recombinant DNA**.

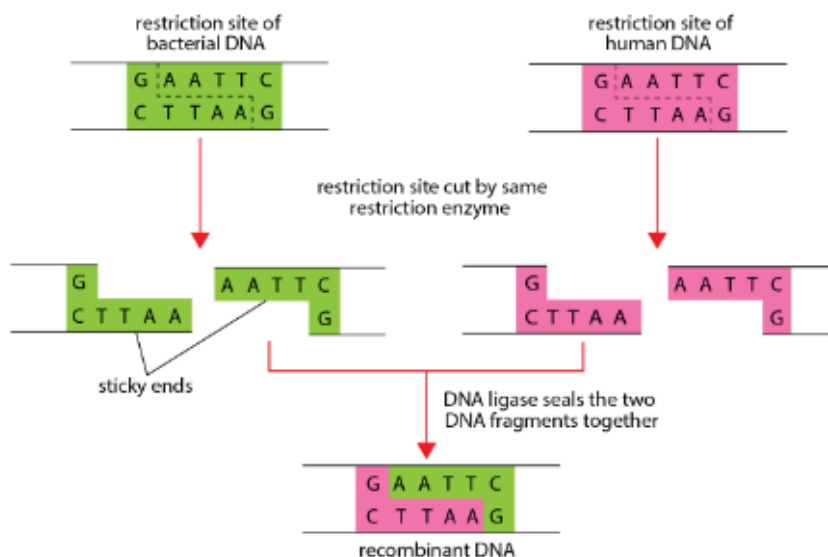


Figure 14.12 How recombinant DNA is made

Producing Transgenic Bacteria to Manufacture Insulin

A transgenic bacterium can be genetically engineered to express the gene for human insulin. Figure 14.13 shows how a gene-of-interest, i.e. the human insulin gene, is transferred to a bacterium.

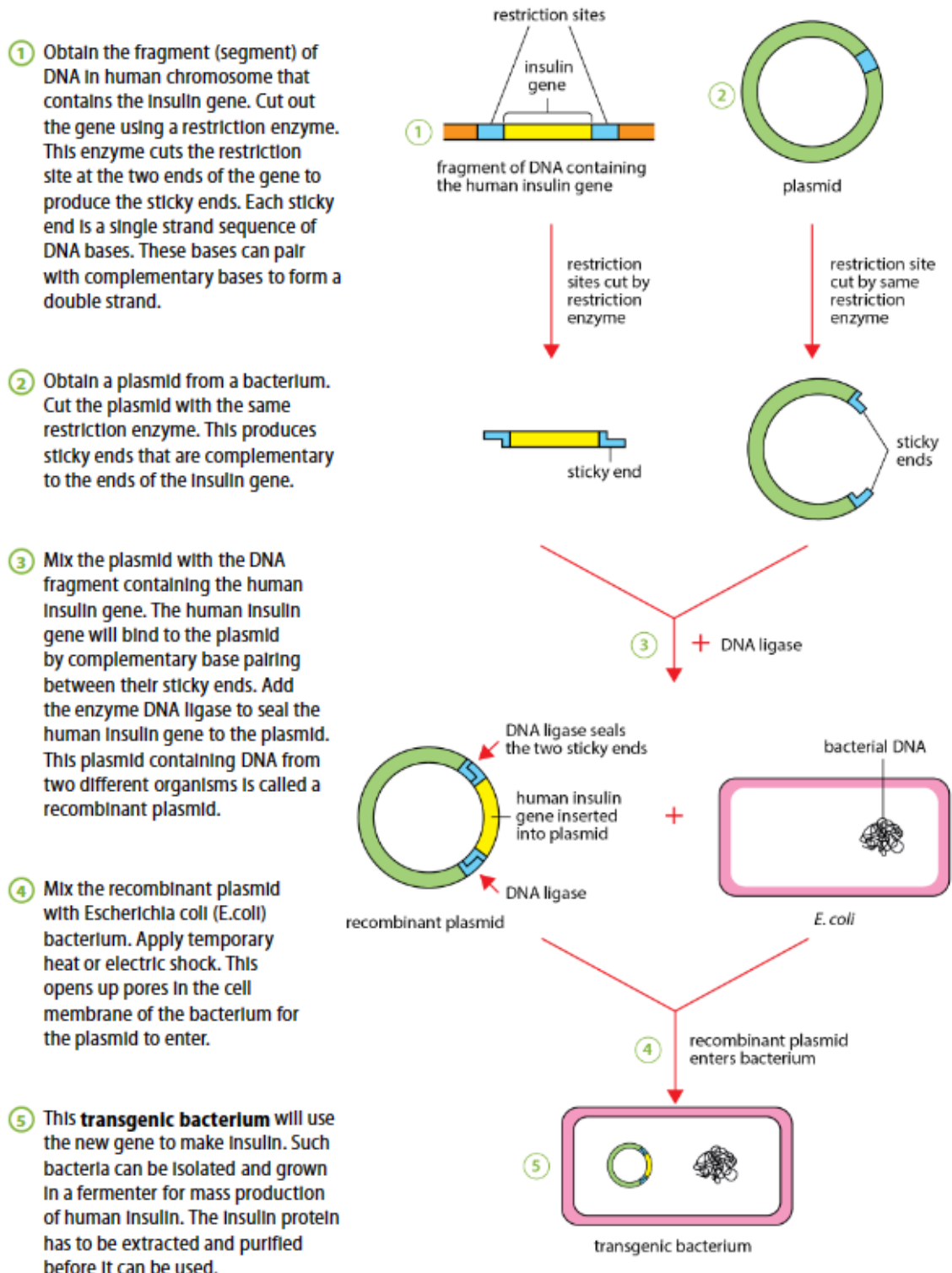


Figure 14.13 How the human insulin gene is inserted into bacterial DNA

Let's Practise 14.3

- 1 Explain what is meant by *transgenic organism*.
- 2 State **two** advantages of producing insulin by genetic engineering over the use of insulin obtained from animals.

14.4 What Are the Considerations Surrounding Genetic Engineering?

Learning Outcome

- Discuss the possible benefits and ethical considerations of genetic engineering, in medicine and production of economically important plants and animals.

Genetic engineering has been shown to offer a lot of possibilities to solve our worldly problems. It can be used to eliminate unwanted traits such as diseases. It can help to breed healthier and sturdier plants and animals. As with all things, it does come with its pros and cons. Are we making our world 'perfect' with genetic engineering or are we opening a can of worms?

What Are the Benefits of Genetic Engineering?

You have learnt that genetic engineering can be used to produce drugs such as insulin. Genetic engineering has also been used to make plants more resistant to pests or tolerant to herbicides. In recent years, genetic engineering has also been used to help environmental scientists monitor and solve many problems related to environmental damage. Table 14.1 summarises the benefits of some applications of genetic engineering.

Table 14.1 Benefits of genetic engineering

Applications of Genetic Engineering	Benefits to Society
Low-cost production of medicines	Genetic engineering of important drugs such as human insulin has drastically reduced the cost of these medicines. With these drugs becoming more affordable, more patients can get access to them and be treated.
Production of crops that grow in extreme conditions, for example: • drought-resistant crops • salt-tolerant crops • crops that make more efficient use of nutrients	This allows farmers to grow crops even when the environmental conditions are not suitable for cultivating most crops.
Development of: • crops that produce toxins that kill insect pests • pesticide-resistant crops	The use of costly pesticides that may damage the environment is reduced. For example, the Bt gene from a certain bacterium can be inserted into plants to produce a toxin that kills certain insect pests.
Development of foods designed to meet specific nutritional goals	This has improved the nutritional quality of foods. For example, two genes from daffodil and one gene from the bacterium <i>Erwinia uredovora</i> inserted into rice plants produce 'Golden Rice'. The rice grains have high vitamin A content.



Tech Connect

Up till recently, doctors would prescribe similar medicines and treatment programmes to patients suffering from the same disease. This method might not work for all patients as they may respond differently to the same medicine due to their different genetic makeups.

We now have a better understanding of how genes and proteins direct the different biological processes in our bodies. With this advancement, hospitals have started to design medication programmes that are customised to each patient, based on the individual's genetic profile. Each programme could differ in the type and amount of medicine, the timing for medication, and many other aspects. This enables doctors to treat each patient more effectively, targeting the medication where it matters most.

What Are Some Ethical Considerations of Genetic Engineering?

Although genetic engineering improves the quality of human life, it has also resulted in many ethical issues in society. Thus, there is a need to consider these ethical issues before any decision is made to proceed with genetic engineering in a particular area. Some examples of ethical considerations are listed below:

- 1 New proteins in GM foods might cause allergies in humans that consume them. There needs to be more studies on how GM food can affect human health.
- 2 Some biotechnology companies have engineered crop plants such that these plants produce seeds that cannot germinate. This means that farmers have to buy special seeds from these companies every year (Figure 14.15). This poses a serious problem to poorer societies, where farmers are struggling to make a living.



Figure 14.14 People protesting against foods derived from genetically modified organism or GMO foods (also GM foods)



Figure 14.15 Some biotech companies have developed GM crops that produce seeds that cannot germinate. This way they can make a profit from selling special seeds to farmers.

- 3 Animals are often used in medical research to study diseases. For example, the oncomouse is a transgenic mouse into which a gene that causes cancer has been introduced. The mouse develops cancer for use in testing potential cancer drugs. When carrying out such research, considerations for the welfare of the animals should be made.
- 4 Some people may deliberately create new combinations of genes which they may use in chemical or biological warfare (Figure 14.17).
- 5 Genes that code for antibiotic resistance may be used in genetic engineering. There is concern that such genes might accidentally be incorporated into bacteria that cause diseases to humans, making antibiotics ineffective in treating these diseases.
- 6 Genetic engineering may not be equally accessible to everyone. Only individuals with sufficient financial means can afford certain gene technologies.



Figure 14.16 White mice are often used in genetic engineering experiments.



Figure 14.17 Genetic engineering gives rise to a new kind of warfare where chemicals and bioweapons are being used.

Let's Practise 14.4

- 1 Genetically engineered organisms have been used in agriculture and food production. State **two** possible ethical considerations.



Link

Theory Workbook
Worksheet 14C
Let's Assess
Let's Reflect

Problem-based Learning Activity

You have learnt that foreign proteins can be introduced into the body of a living organism. This can be done by either injecting the proteins into the bloodstream or introducing a genetic material into the cells to produce those proteins.

You have now been tasked to introduce a foreign protein (protein **X**), which can help to prevent a disease, into the human body.

Protein **X** is not naturally made by the human body. You are to suggest how protein **X** can be introduced into human cells without the need to constantly inject large amounts of it into the body.

Protein **X** should only be produced temporarily. There should not be any permanent modification to the cell's genetic material.

Use the following questions as guidelines to discuss:

- 1 Which parts of the cell are involved in protein synthesis?
- 2 How are proteins synthesised?
- 3 Which type of genetic material will be suitable to be introduced into the human body to produce protein **X**? Why?



Link

Theory Workbook
Problem-based Learning
Application



Cool Career

Biochemist

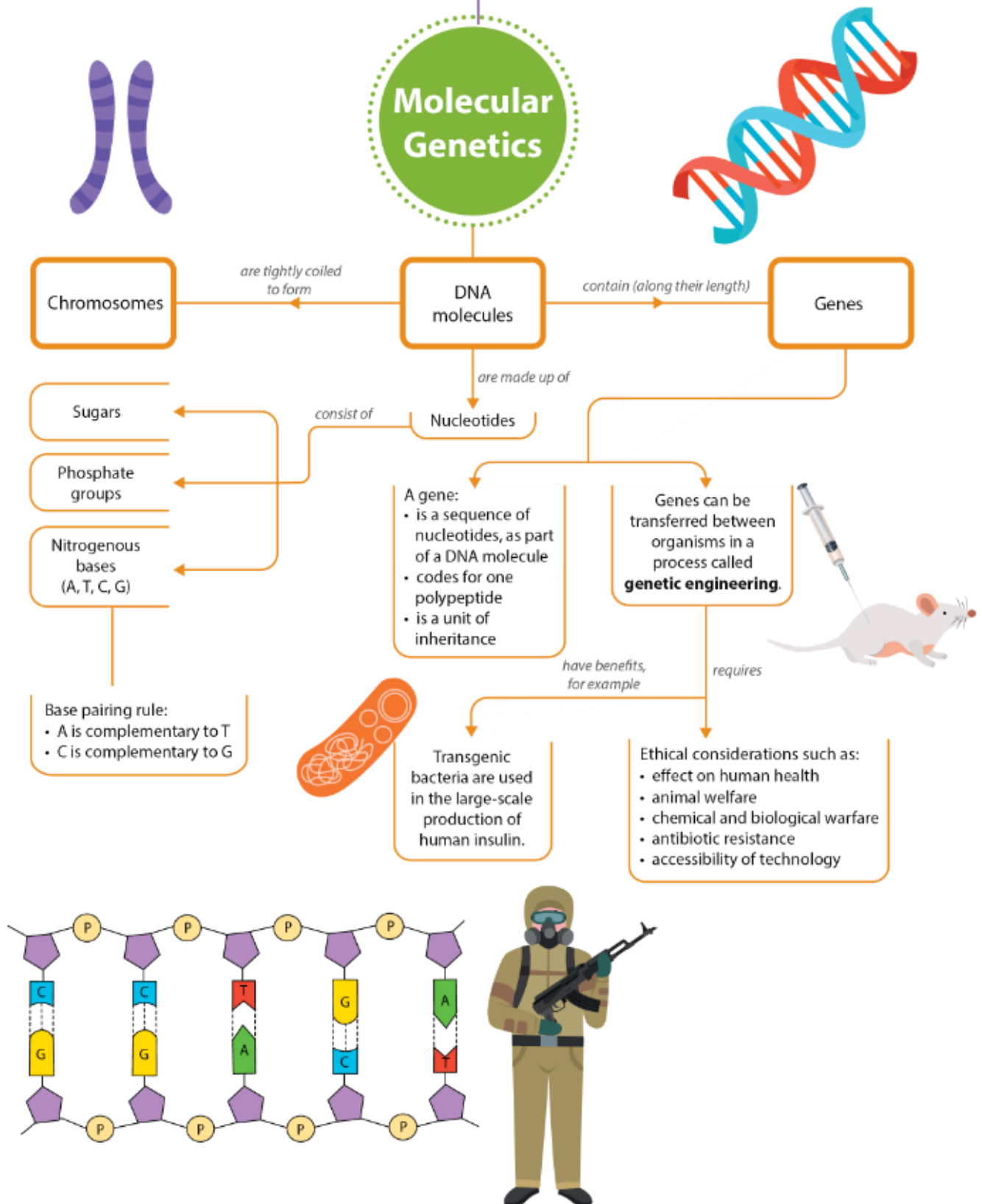
Turning a cancer drug into a COVID-19 vaccine — here's a look at how the creative minds of two scientists led them to design one of the most powerful medical solutions in recent history.

In 2005, Hungarian biochemist Katalin Karikó designed an artificial mRNA molecule. Scientists were then able to transfer this artificial mRNA into cells of mice and humans without activating an immune response that would otherwise block the process. This presented an elegant piece of technology. It can be used to create medicines that cells in human bodies can produce to fight different kinds of diseases — from cancer to influenza infection, and in 2020, vaccines against COVID-19. The path to this phenomenal success was filled with a lot of rejections, humiliation from fellow colleagues who did not believe in her work and also her fight against cancer. Karikó did not give up on her passion and was creative to look for answers in places where others did not think existed.



Figure 14.18 A biochemist does biochemical investigations that can unlock medical solutions for mankind.

Let's Map It



Let's Review

Section A: Multiple-choice Questions

1 Which statement describes a gene?

- ☐ A a sequence of nucleotides
- ☐ B a base with a sugar and a phosphate group
- ☐ C a number of DNA segments
- ☐ D a sequence of amino acids

2 Which statement about DNA is **correct**?

- ☐ A A DNA molecule contains many genes.
- ☐ B A DNA molecule is larger than a chromosome.
- ☐ C All DNA molecules have the same length.
- ☐ D A DNA molecule is slightly larger than a gene.

3 Table 14.2 shows a strand of DNA containing 100 nucleotides.

Table 14.2

Nucleotide	Quantity
Adenine	30
Cytosine	20
Guanine	15
Thymine	35

How many thymine nucleotides will there be on the strand of DNA that is complementary to the strand?

- ☐ A 15
- ☐ B 20
- ☐ C 30
- ☐ D 35

4 Here are some statements about the production of human insulin by genetic engineering.

- 1 The insulin gene is cut out from human DNA.
- 2 A bacterial plasmid is cut open.
- 3 The plasmid is inserted into a bacterium.
- 4 The insulin gene is inserted into a plasmid.

What is the **correct** sequence of these statements?

- ☐ A 1, 2, 4, 3
- ☐ B 1, 3, 2, 4
- ☐ C 2, 1, 3, 4
- ☐ D 2, 3, 4, 1

Section B: Structured Questions

1 Scientists in a laboratory carried out an analysis on the nitrogenous bases present in a DNA sample. Due to some technical issues with the apparatus, only the percentage composition of adenine was obtained. Table 14.3 shows their findings.

Table 14.3

Nitrogenous Base	Percentage Composition
Adenine	31.8%
Cytosine	—
Guanine	—
Thymine	—

- (a) Do you think that it is possible for us to obtain the missing information without fixing the apparatus? Explain.
- (b) What is the possible percentage composition of guanine in the DNA sample?

2 Genetic engineering uses enzymes to cut and join sections of DNA.

- (a) Name the enzyme used to cut DNA at a specific site.
- (b) Name the enzyme used to join two sections of DNA.
- (c) Name **one** human hormone that is produced by genetically modified bacteria.

Section C: Free-response Questions

1 Describe the structure of DNA.

2 How do genes store information?

- 3 (a) Outline the basic steps in the transfer of genes between cells.
- (b) What are the advantages of using genetically engineered bacteria for the commercial preparation of human insulin over the older methods?

4 Discuss **two** ethical considerations of genetic engineering.

CHAPTER

15 Modes of Reproduction



What You Will Learn



- What is asexual reproduction?
- What is sexual reproduction?

When attacked by predators, puffer fish puff themselves up by swallowing water. Can this increase in size be regarded as growth?

A female puffer fish can lay as many as 200 000 eggs. Each egg has a diameter of about 0.95 mm. Puffer fish eggs take five days to hatch. The fish larvae that emerge measure about 2.4 mm in length. By the time the larvae reach a length of 7 mm, they possess many adult characteristics such as the ability to puff themselves up when threatened. As the puffer fish eggs change into larvae and then into adult fish, they undergo increases in size. Are these increases in size regarded as growth? What has caused these increases in size to occur?



15.1 What Is Asexual Reproduction?

Learning Outcomes

- Define *asexual reproduction*.
- State that mitosis is a type of cell division giving rise to genetically identical cells in which the chromosome number is maintained.
- State the importance of mitosis in growth, repair and asexual reproduction.

Have you tried growing spring onions at home? Try growing some spring onion bulbs in a pot of soil. Water the bulbs regularly. You will find that roots and shoots will develop. The new plants that develop are genetically identical. They will in turn produce new plants like themselves. This is an example of asexual reproduction.



Helpful Note

Sperm and egg cells are gametes.

► **Asexual reproduction** is the process that results in the production of genetically identical offspring from one parent, without the fusion of gametes.

Asexual reproduction involves mitosis. The offspring produced asexually are genetically identical to the parent.

What Is Mitosis?

Figure 15.1 shows what happens when a nucleus divides by mitosis.

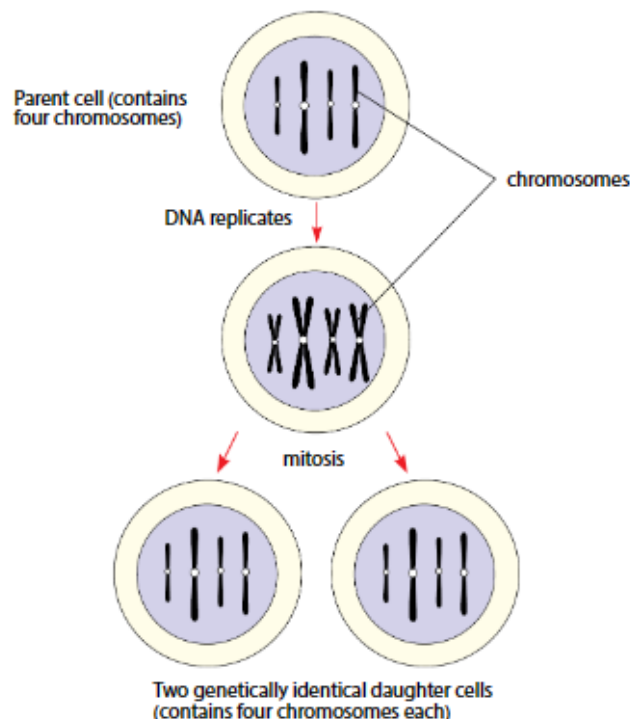


Figure 15.1 Mitosis results in two identical daughter cells.

► **Mitosis** is a type of cell division giving rise to genetically identical cells in which the chromosome number is maintained.



Why Is Mitosis Important?

Other than asexual reproduction, mitosis also occurs in other processes.

Mitosis is important in:

- **Asexual reproduction**
Mitosis allows for asexual reproduction to occur.
- **Growth in multicellular organisms**
For a multicellular organism to grow, new cells must be produced by mitosis.
- **Repair of damaged tissues**
New cells are produced by mitosis to replace cells that are dead or damaged.



Disciplinary Idea

The Cell

For organisms to grow and develop, their cells must divide by mitosis to give rise to genetically identical cells.

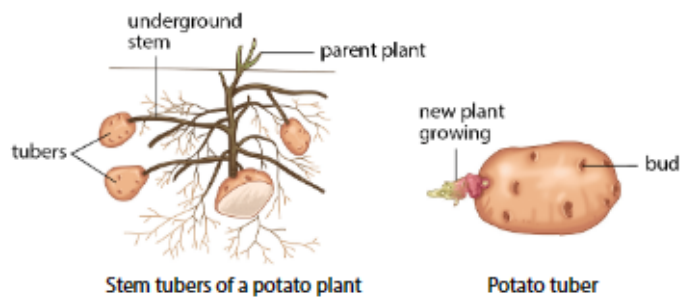
What Are Some Examples of Asexual Reproduction?

Some plants are able to reproduce asexually. Figure 15.2 shows some examples of the methods of asexual reproduction in plants.

Examples of Asexual Reproduction in Plants

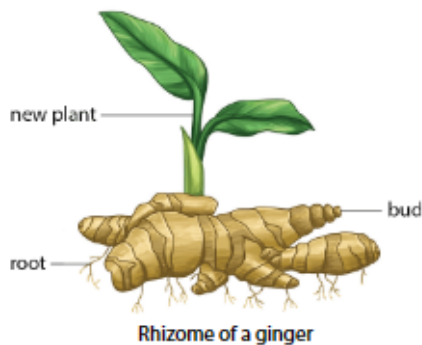
Stem tuber

A stem tuber is the swollen end of an underground stem. It has many buds. During favourable seasons, the buds will use up the food stored in the tuber to grow into new plants. There will be as many new plants as there are buds. Potato tubers are stem tubers.



Rhizome

A rhizome is an underground storage stem. It bears scale leaves and buds. Each bud can grow into a new plant.



Runner

A runner is a slender shoot that arises from a bud in the parent plant. It grows horizontally over the surface of the soil. Buds develop along its length. Each bud develops roots and leaves, and becomes a new plant.

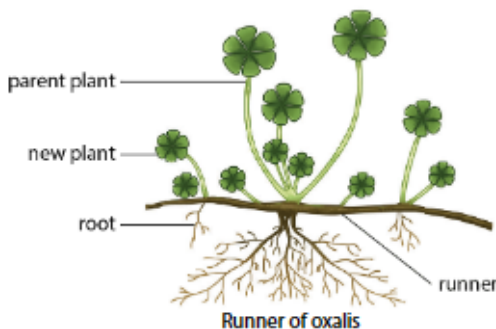


Figure 15.2 Asexual reproduction in plants

What Are the Advantages and Disadvantages of Asexual Reproduction?

Some advantages and disadvantages of asexual reproduction are listed in Table 15.1.

Table 15.1 Advantages and disadvantages of asexual reproduction

Advantages	Disadvantages
• Only one parent is required. • Fusion of gametes is not required. • All the beneficial qualities are passed on to the offspring. • This method of producing offspring is faster than sexual reproduction.	• There is no genetic variation in offspring. Hence, species are not well-adapted to changes in the environment. For example, if the parent does not have resistance to a particular disease, the offspring too would not have resistance to the disease. This means that the whole population of plants could be wiped out by a particular disease.

Let's Practise 15.1

- 1 Define the term *asexual reproduction*.
- 2 Explain what *mitosis* is.

15.2 What Is Sexual Reproduction?

Learning Outcomes

- Define *sexual reproduction*.
- Define the terms *haploid* and *diploid*, and explain the need for a reduction division process prior to fertilisation in sexual reproduction.
- State what is meant by homologous pairs of chromosomes.
- State that meiosis is a type of cell division that gives rise to genetically dissimilar cells in which the chromosome number is halved due to the separation of homologous chromosomes.
- State that meiosis is used in the formation of gametes.



Disciplinary Idea

The Cell

Sexual reproduction involves the fusion of sex cells (a male and female gamete) to form a zygote (a cell formed after fertilisation).

You have learnt about one mode of reproduction, which is *asexual reproduction*. There is another mode of reproduction called *sexual reproduction*.

- **Sexual reproduction** is a process involving the fusion of two gametes to form a **zygote**. It produces genetically dissimilar offspring.

In humans, the sperm is the male gamete, and the egg is the female gamete. Gametes contain half the number of chromosomes as normal body cells. This is because gametes are produced by a process called *meiosis*.

What Is Meiosis?

Consider a cell containing two pairs of chromosomes (Figure 15.3). For each pair of chromosomes, one chromosome is inherited from the male parent and the other from the female parent. They have the same shape, size and the same sequence of genes. They are called **homologous chromosomes**.

During meiosis, the parent cell divides to produce four daughter cells that are genetically dissimilar.

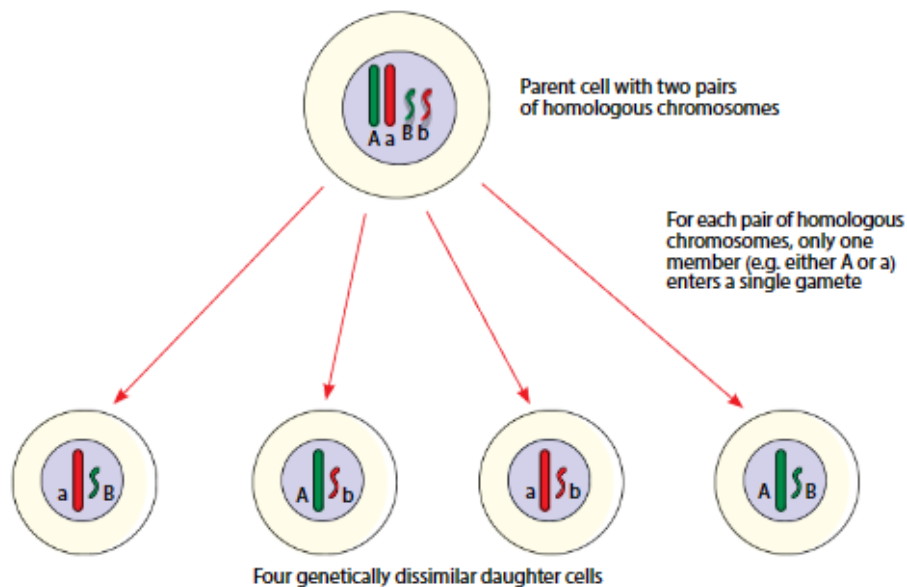


Figure 15.3 Meiosis results in four genetically dissimilar daughter cells.

Notice that each gamete contains half the number of chromosomes as the parent cell. Hence, meiosis is a **reduction division**.

► **Meiosis** is a type of cell division that gives rise to genetically dissimilar cells in which the chromosome number is halved due to the separation of homologous chromosomes.



Link

Go to Chapter 17 to find out more about human reproduction.

Learn more about how traits are passed on from parents to their offspring in Chapter 18.

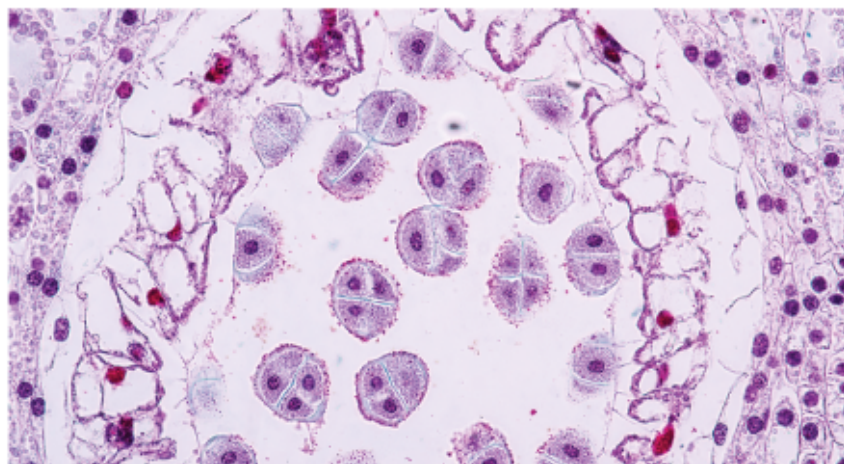


Figure 15.4 Cells undergoing meiosis



Disciplinary Idea

Heredity

Meiosis halves the number of chromosomes in gametes to ensure that when two gametes fuse during fertilisation, the organism has the same number of chromosomes at every subsequent generation.

What Is the Difference Between a Haploid Cell and a Diploid Cell?

Consider a male gamete and a female gamete. Each contains one set of three chromosomes (shown in Figure 15.5 in either blue or red). During fertilisation, the male gamete fuses with the female gamete.

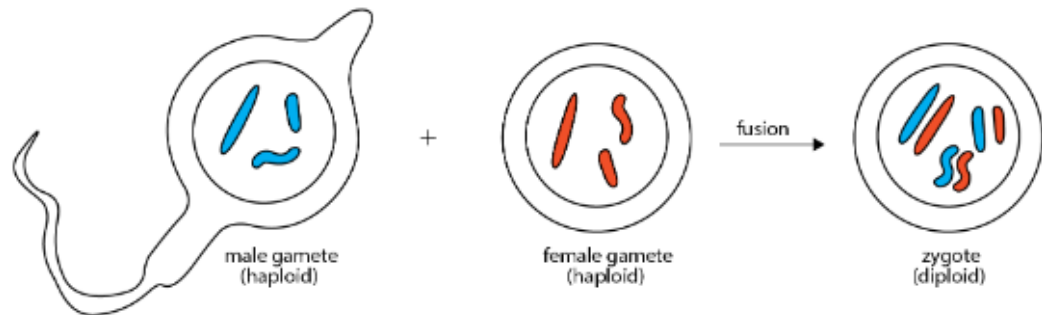


Figure 15.5 Fertilisation of male and female gametes

The fertilised female gamete or zygote produced will contain two sets of chromosomes. Hence, the zygote has three pairs of chromosomes.

A **haploid** cell (e.g. a gamete) is a cell with one set of chromosomes.

A **diploid** cell (e.g. zygote) is a cell with two sets of chromosomes, one set from the male parent and the other from the female parent.

Why Is Meiosis Important?

Meiosis is important in the following ways:

- **Meiosis produces haploid gametes.**

During meiosis, each pair of homologous chromosomes in the parent nucleus separates to form daughter cells. Each daughter cell only receives one copy of the homologous chromosomes, i.e. haploid number of chromosomes. During fertilisation, when the nucleus of the male gamete fuses with the nucleus of the female gamete, the normal diploid number of chromosomes is restored in the zygote.

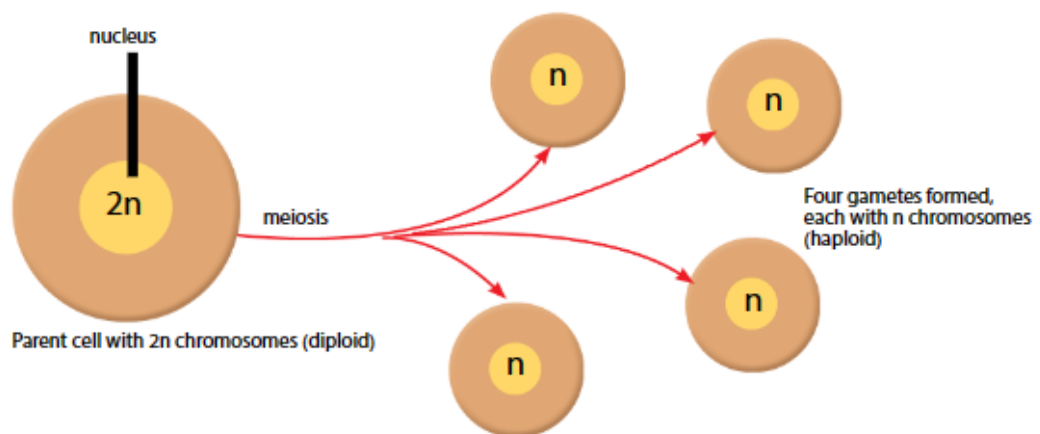


Figure 15.6 Production of haploid gametes



- **Meiosis produces gametes that are genetically dissimilar.**
The greater the genetic variations, the better the species is adapted to changes in the environment. For example, if organisms of a species are genetically similar, any change in the environment may wipe out the whole population. If one organism dies because of the change in the environment, all other organisms within the same species will also die. If organisms of the same species are varied, it is unlikely that a change in the environment will destroy the whole species. Those that survive will pass on their favourable genes to their offspring.

What Are the Advantages and Disadvantages of Sexual Reproduction?

Some advantages and disadvantages of sexual reproduction are listed in Table 15.2.

Table 15.2 Advantages and disadvantages of sexual reproduction

Advantages	Disadvantages
• Offspring may inherit beneficial qualities from both parents. • There is genetic variation in the offspring that is better adapted to changes in the environment.	• Two parents are required (except in plants with bisexual flowers). • Fusion of gametes is required. • This method of producing offspring is slower than asexual reproduction.

What Are the Differences Between Asexual and Sexual Reproduction?

Table 15.3 summarises key differences between asexual and sexual reproduction.

Table 15.3 Differences between asexual reproduction and sexual reproduction

Asexual Reproduction	Sexual Reproduction
Does not involve the fusion of gametes	Involves the fusion of a male gamete with a female gamete to form a zygote
Requires only one parent	Requires two parents (except for plants with bisexual flowers)
Offspring are genetically identical to the parent	Offspring are genetically dissimilar to the parent
Relatively quicker method of producing offspring	Slower method of producing offspring



Disciplinary Idea

Heredity

Both sexual and asexual reproduction facilitate the transfer of genetic information from one generation to another.

Let's Practise 15.2

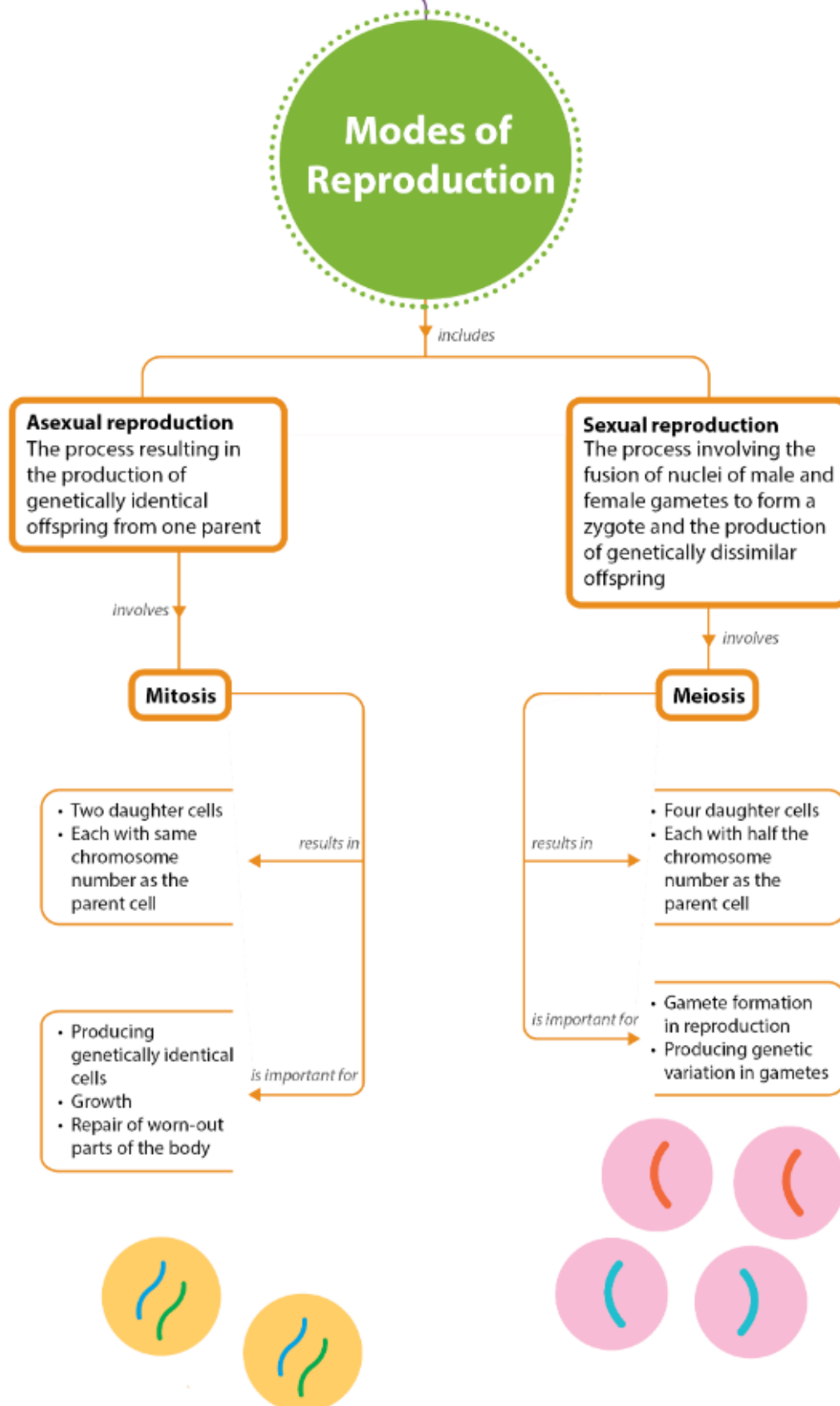
- 1 Define the following terms:
 - (a) sexual reproduction
 - (b) meiosis
- 2 What are homologous chromosomes?
- 3 State the importance of meiosis.
- 4 If the normal cell of a plant has 20 chromosomes, how many chromosomes would each daughter cell have after meiosis?



Link

Theory Workbook
Worksheet 15A

Let's Map It



Let's Review



Section A: Multiple-choice Questions

- 1 Mitosis occurs during the growth of human tissues. The number of chromosomes present in each parent cell before mitosis, and each daughter cell after mitosis is best represented by _____.

- ☐ A $n \rightarrow n$
- ☐ B $n \rightarrow 2n$
- ☐ C $2n \rightarrow n$
- ☐ D $2n \rightarrow 2n$

- 2 Meiosis occurs during the production of human gametes. The number of chromosomes present in each cell before and after meiosis is best represented by _____.

- ☐ A $n \rightarrow n$
- ☐ B $n \rightarrow 2n$
- ☐ C $2n \rightarrow n$
- ☐ D $2n \rightarrow 2n$

- 3 Homologous chromosomes _____.

- ☐ A exist in pairs in gametes
- ☐ B have the same sequence of genes
- ☐ C are identical for all members of a species
- ☐ D come from one parent during sexual reproduction

Section B: Structured Questions

- 1 (a) State the **two** modes of reproduction.
 (b) For each mode in (a), give **one** advantage and **one** disadvantage.
- 2 What is the difference between
 (a) mitosis and meiosis;
 (b) haploid and diploid number of chromosomes?

Section C: Free-response Questions

- 1 State the importance of mitosis in life.
- 2 Why is reduction division important in organisms that reproduce sexually?

CHAPTER

16 Reproduction in Plants



What You Will Learn



- What are the parts of a flower?
- What is pollination?
- What happens after pollination?

Have you ever noticed that some plants have big, colourful flowers?

These colourful flowers attract insects such as bees and butterflies.

However, other plants may only have tiny, delicate flowers or no flowers at all. Why do you think there is such a difference?

16.1 What Are the Parts of a Flower?

Learning Outcomes

- Identify using a hand lens if necessary, the sepals, petals, stamens and carpels of insect-pollinated, dicotyledonous flowers, and examine the pollen grains under a light microscope.
- State the functions of the sepals, petals, anthers and carpels.
- Identify using a hand lens if necessary, the stamens and stigmas of wind-pollinated flowers, and examine the pollen grains under a light microscope.

Flowers are lovely to look at. It is not difficult to notice that flowers from different plants have a wide variety of shapes and forms. Nevertheless, they generally have the same parts. What are these parts and what are their functions?

Flowers bear the reproductive parts of flowering plants. Flowers may occur singly on plants or in clusters called inflorescences (Figure 16.1). An inflorescence is a cluster of flowers borne on the same stalk.

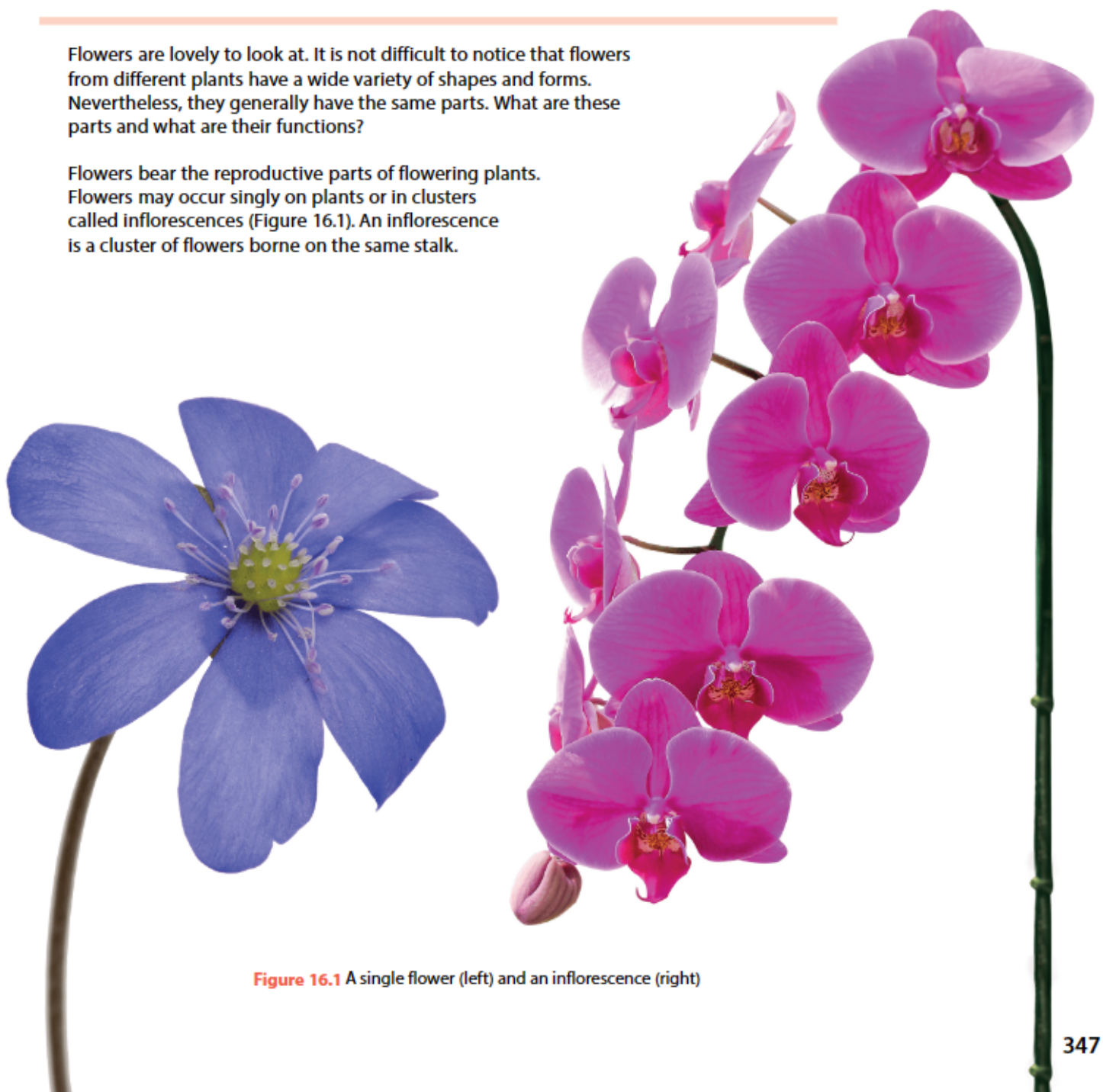
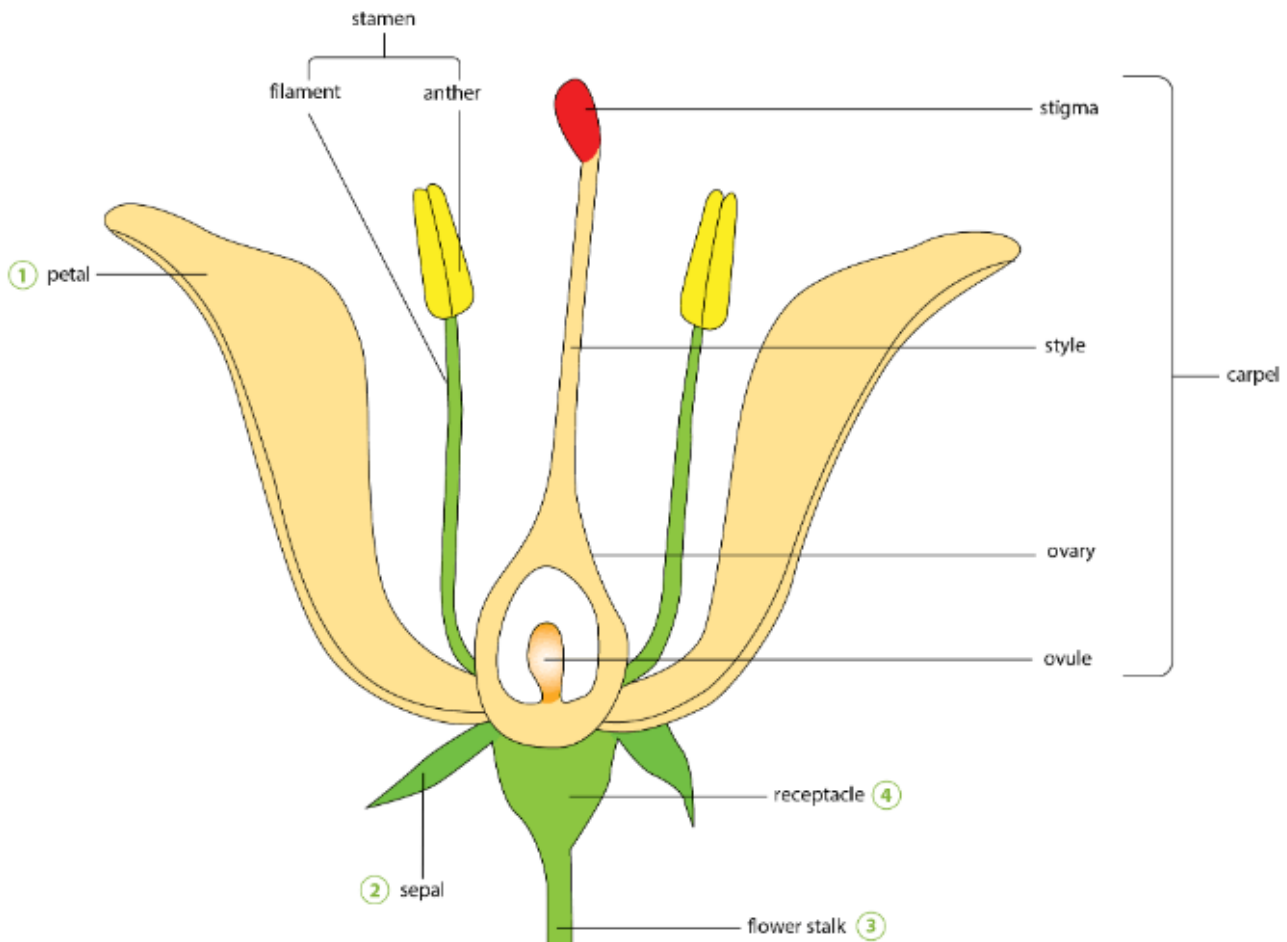


Figure 16.1 A single flower (left) and an inflorescence (right)



A complete flower consists of the following parts: **flower stalk, receptacle, sepals, petals, stamens** and **carpels (pistils)**. Figure 16.2 shows the structure of a typical flower.



① **Petal**

Petals are modified leaves forming the most obvious (conspicuous) part of the flower. In insect-pollinated flowers, petals:

- are brightly coloured to attract insects for pollination
- provide a platform for insects to land
- have lines that guide insects to the base of the petals to obtain nectar

② **Sepal**

Sepals are modified leaves which enclose and protect the other parts of the flower in the **bud** stage. The sepals usually form the outermost layer of floral leaves.

③ **Flower stalk**

The flower stalk attaches the flower to the stem. Some flowers have no stalks and are attached to the plant directly at the base.

④ **Receptacle**

The receptacle is the swollen end of the flower stalk.



Disciplinary Idea

Systems

The reproductive system in plants consists of various organs that work together to facilitate reproduction.

Figure 16.2 Structure of a typical flower

Stamen

The stamen is the male part of the flower. The stamen consists of an **anther** and a **filament** (Figure 16.3).

- ① **Filament**
The filament is the stalk that holds the anther in a suitable position to disperse the pollen.

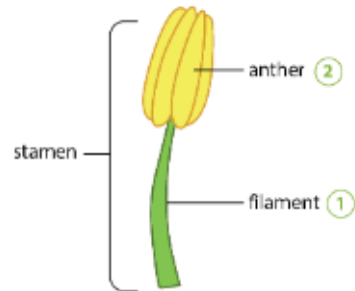
- ② **Anther**
The anther produces pollen grains. When the anther matures, it splits open to release the pollen grains.

- ③ **Pollen grains**
Pollen grains contain the male gametes. The male gametes are produced by meiosis and are haploid. They have half the number of chromosomes as a normal cell. If the normal cell of a plant has 20 chromosomes, the gamete will have 10 chromosomes.



Link

Recall from Chapter 12 about transport in plants.



Side view of a stamen

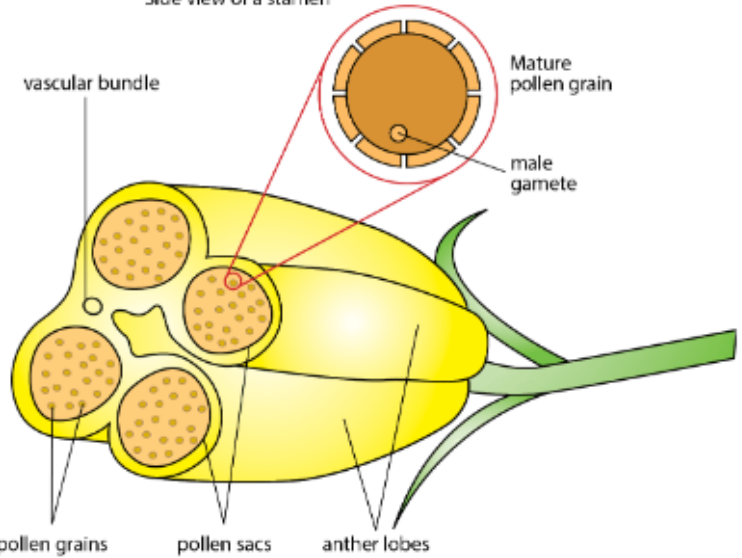
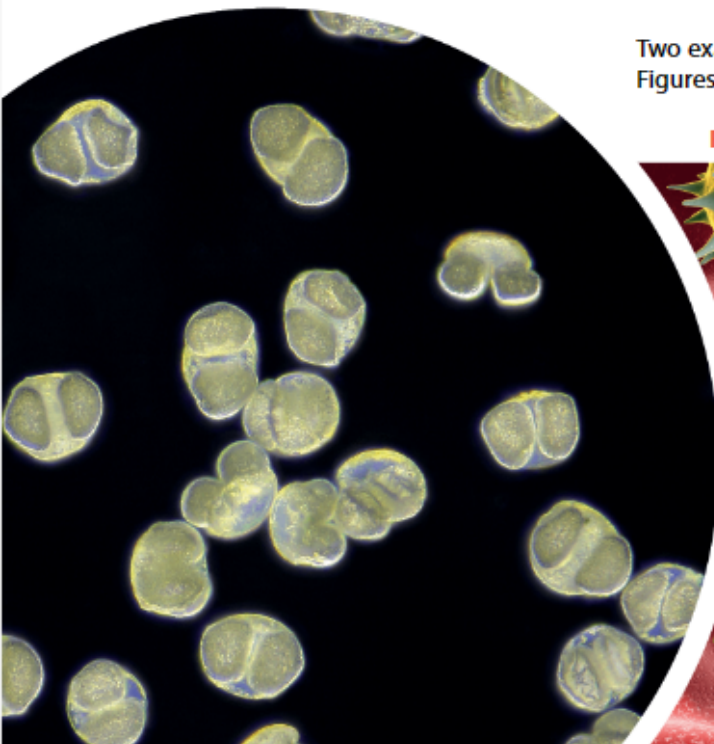


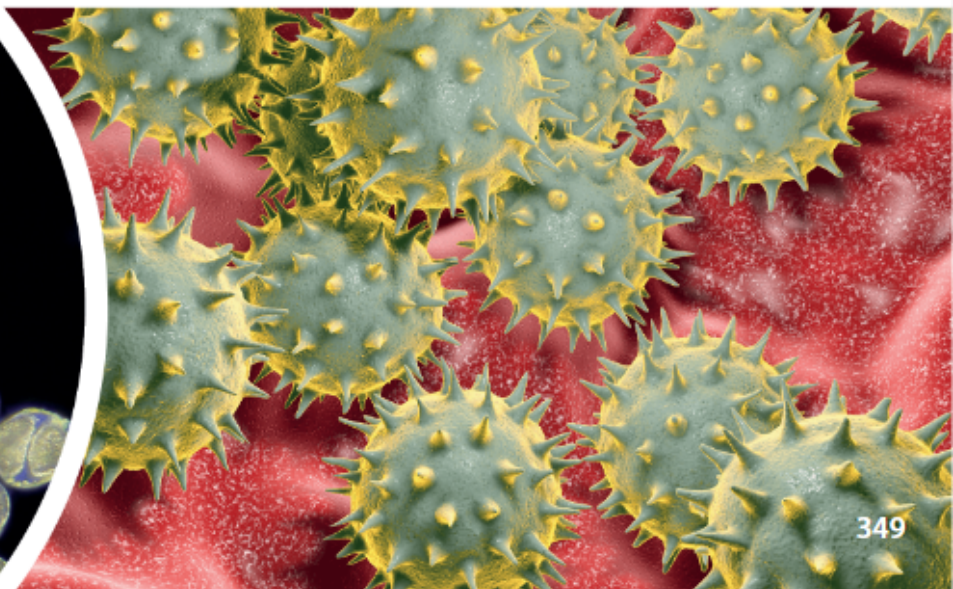
Figure 16.3 Parts of a stamen

Figure 16.4
Microscopic view
of wind-pollinated
pollen grains



Two examples of pollen grains are shown in Figures 16.4 and 16.5.

Figure 16.5 Microscopic view of insect-pollinated pollen grains



Carpel (Pistil)

The carpel or pistil is the female part of the flower. A carpel consists of an **ovary**, a **style** above the ovary, and a **stigma** (Figure 16.6).

1 Stigma

The stigma is a swollen structure at the end of the style. It receives the pollen grains. The mature stigma secretes a sugary fluid that stimulates the pollen grains to germinate (see Section 16.3).

2 Style

The style is a stalk that connects the stigma to the ovary. It holds the stigma in a suitable position to trap pollen grains. You will learn more about this later in this chapter.

3 Ovary

The ovary contains one or more **ovules**. Within each mature ovule is a female gamete or egg cell called the **ovum** (plural: **ova**). The ovum is produced by meiosis. It is therefore haploid.

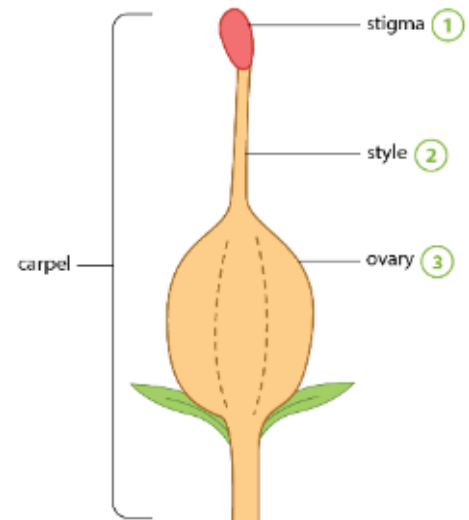
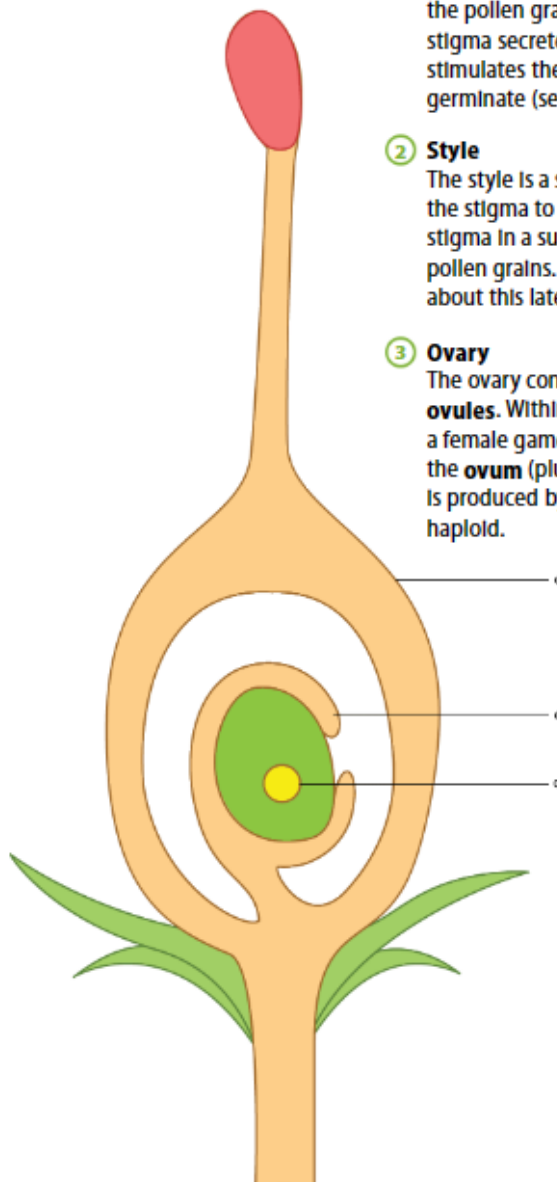


Figure 16.6 Parts of a carpel



Link

Theory Workbook
Worksheet 16A

Let's Practise 16.1

1 State the functions of these flower parts of an insect-pollinated flower.

- (a) sepal
- (b) petal
- (c) anther
- (d) stigma

16.2 What Is Pollination?

Learning Outcomes

- Outline the process of pollination and distinguish between self-pollination and cross-pollination.
- Compare, using fresh specimens, an insect-pollinated and a wind-pollinated flower, and explain their differences.

Seeing insects visiting different flowers is a common sight in gardens. These are not casual visits. They mean business. Flowers of plants have developed characteristics to attract insects. Some go all the way to lure only certain kinds of insects. Why do flowers have features to attract insects?

In order for flowering plants to reproduce sexually, the pollen grains must be transferred from the anthers to the stigmas so that the male gamete (in the pollen grain) can meet the female gamete (in the ovule). This transfer of pollen grains is called *pollination* (Figure 16.7).

► **Pollination** is the transfer of pollen grains from the anther to the stigma.

There are two types of pollination: *self-pollination* and *cross-pollination*.

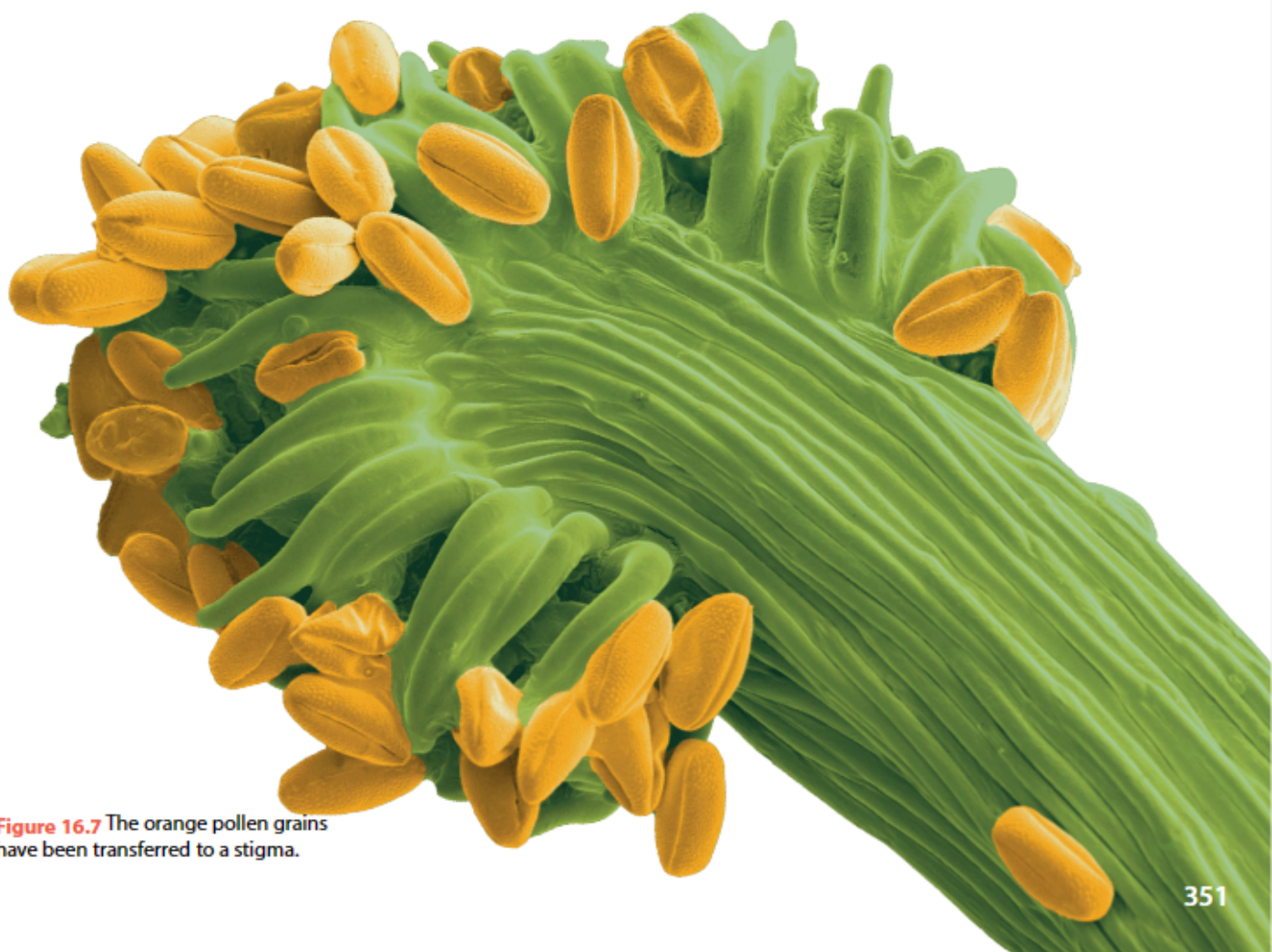


Figure 16.7 The orange pollen grains have been transferred to a stigma.

What Is Self-pollination?

Self-pollination is the transfer of pollen grains from the anther to the stigma of the same flower or of a different flower on the same plant.



Word Alert

Bisexual: having male and female reproductive parts in the same organism

What Features Favour Self-pollination?

The following are some features of flowers that favour self-pollination (Figure 16.8):

- Flowers are **bisexual** with anthers and stigmas maturing at the same time.
- The stigma is situated directly below the anthers.
- In certain plants with bisexual flowers, some flowers never open. Only self-pollination can occur in these flowers.

What Are the Advantages and Disadvantages of Self-pollination?

Table 16.1 shows some advantages and disadvantages of self-pollination.

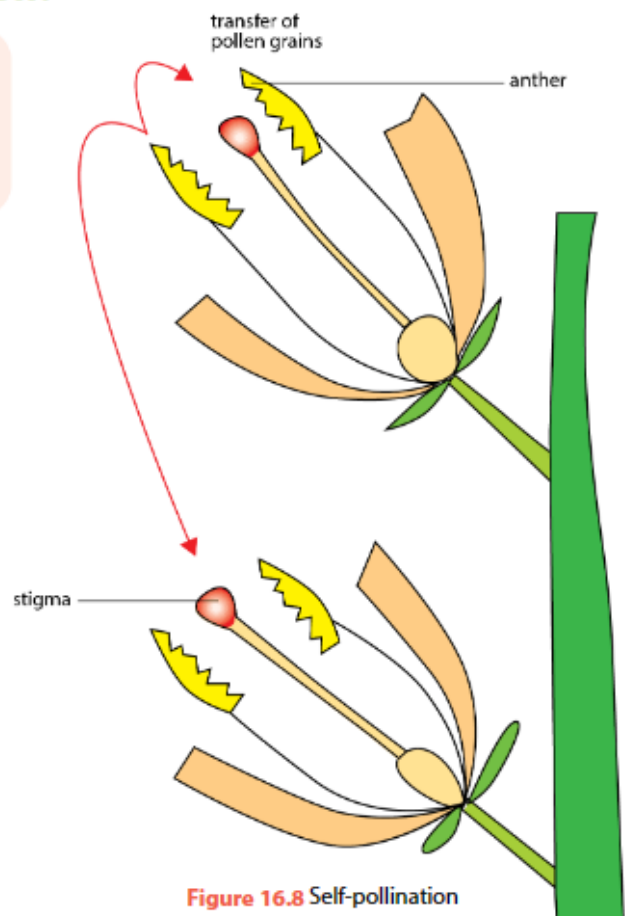


Figure 16.8 Self-pollination

Table 16.1 Advantages and disadvantages of self-pollination

Advantages	Disadvantages
• Only one plant is required. • The offspring inherits its genes from the parent plant after fertilisation. Hence, beneficial qualities are more likely to be passed down to the offspring. • It does not need to depend on external factors such as insects or wind for pollination. • Since the anthers are close to the stigmas of the same flower, there is a higher probability that pollination will occur, as compared to cross-pollination. • Less pollen and energy are wasted in self-pollination as compared to cross-pollination.	• Should fertilisation occur, there will be less genetic variation in the offspring as compared to cross-pollination. The species is less well-adapted to changes in the environment. • Continued self-pollination may lead to the offspring becoming weaker, smaller and less resistant to diseases.



What Is Cross-pollination?

- **Cross-pollination** is the transfer of pollen grains from one plant to the stigma of a flower in another plant of the same species.

What Features Favour Cross-pollination?

The following are some features of flowers that favour cross-pollination (Figure 16.9):

- Some plants, e.g. papaya, bear either male or female flowers. This type of plants cannot undergo self-pollination.
- In many plants with bisexual flowers, the anthers and the stigmas may mature at different times.
- The stigmas of plants with bisexual flowers may be situated some distance away from the anthers so that self-pollination is unlikely.

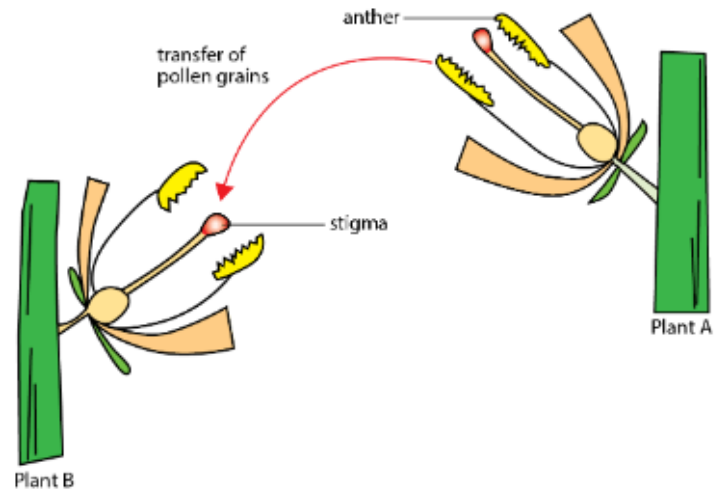


Figure 16.9 Cross-pollination

What Are the Advantages and Disadvantages of Cross-pollination?

Table 16.2 shows some advantages and disadvantages of self-pollination.

Table 16.2 Advantages and disadvantages of cross-pollination

Advantages	Disadvantages
• The offspring produced may have inherited beneficial qualities from both parents. • Should fertilisation occur, there will be greater genetic variation in the offspring produced as compared to self-pollination. This increases the chance of the species surviving changes in the environment because any change in the environment is less likely to destroy all the varieties in a species. • More viable seeds are produced. Such seeds are capable of surviving longer before germination.	• Two plants are required. • It depends on external factors such as insects or wind for pollination. • Since the pollen grains have to be transferred from the anther of one plant to the stigma of another plant, there is a lower probability that pollination will occur, as compared to self-pollination. • More energy and pollen are wasted as compared to self-pollination.



Link

Learn about genetic variation in Chapter 18.

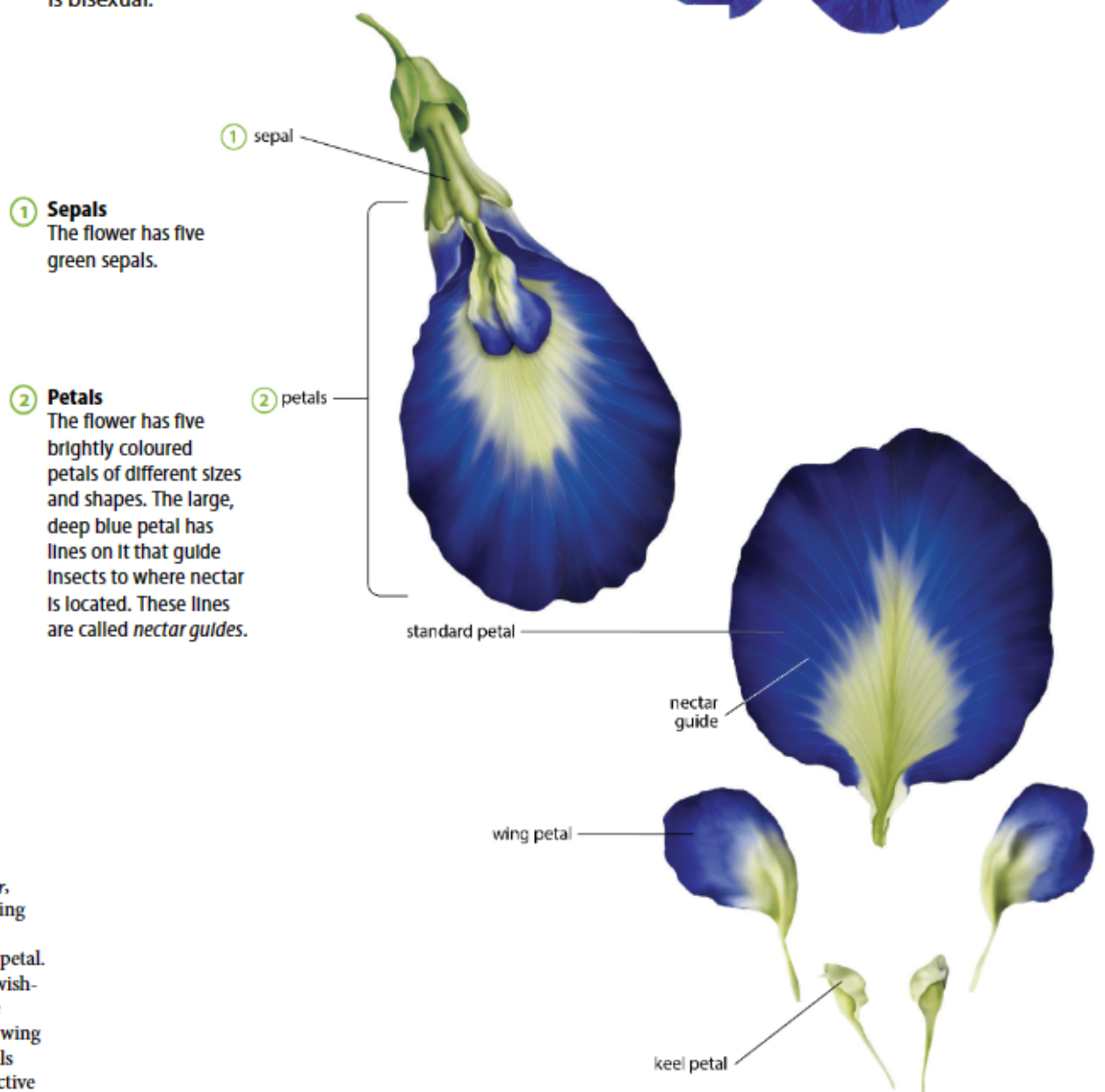
How are pollen grains transferred to the stigma of a flower? This can occur with the help of agents such as insects and wind.



What Are the Structural Adaptations of an Insect-pollinated Flower?

Structure of *Clitoria* (Blue Pea) Flower

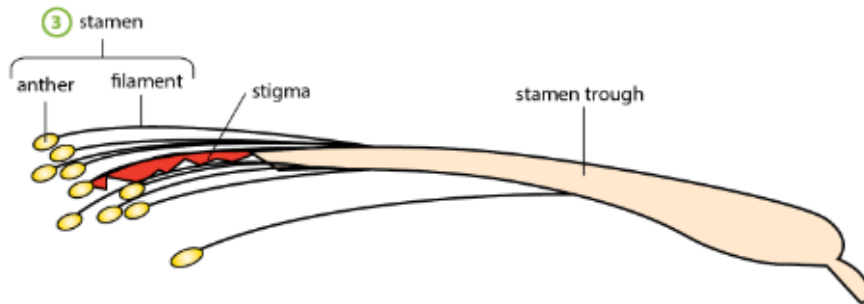
Figure 16.10 shows the *Clitoria* (Blue Pea) flower, which is specially adapted for pollination by insects. The flower is bisexual.



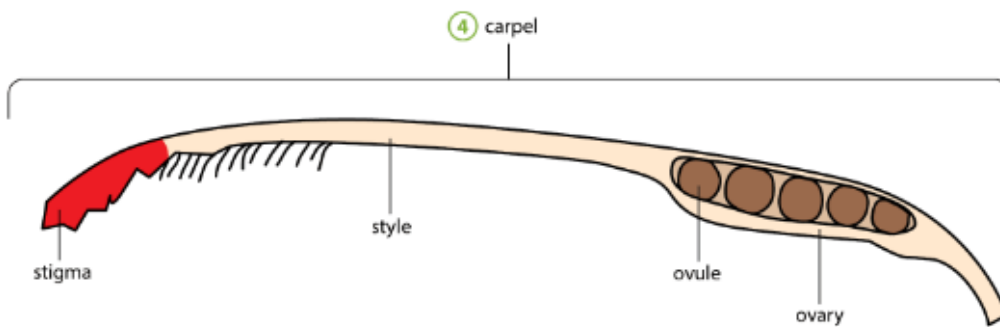
Helpful Note

In the *Clitoria* flower, the two deep blue wing petals are enclosed within the standard petal. The two small yellowish-green keel petals are enclosed within the wing petals. The keel petals enclose the reproductive organs.

Figure 16.10 External features of a *Clitoria* flower



Stamens of the *Clitoria* flower: Parts of the stamen are coloured to indicate their locations.



Carpel of the *Clitoria* flower: Parts of the carpel are coloured to indicate their locations.



Helpful Note

In the *Clitoria* flower, there are 10 stamens. Nine of the stamens are fused along most of their length to form a trough (hollow tube). This trough encloses the carpel (pistil).



Word Alert

Tubular: shaped like a tube



Link

Practical Workbook
Experiment 16A

3 Stamen

The flower has stamens with long filaments. Nectar, secreted by the flower, collects at the bottom of the stamen trough. Thus, the nectar can be reached only by an insect with a long **tubular** mouth or proboscis, for example, a bee or a butterfly.

4 Carpel

The carpel (pistil) consists of the following structures:
Stigma — The stigma is small and compact. It is located at the end of the style.
Style — The style is a long, curved, hairy structure.
Ovary — The ovary is long and narrow with a single row of ovules.

Let's Investigate 16.1

Aim

To examine an insect-pollinated flower under a microscope

Procedure

- 1 Using a hand lens, examine and draw the external features of a *Clitoria* flower. You will have to separate the wing petals in order to reveal the keel petals.
- 2 Examine an anther under a microscope.
- 3 Draw a pollen grain, noting its size and shape.

Pollination of *Clitoria*

- When an insect such as a bee visits the flower, it lands on a petal (Figure 16.11).
- The insect follows the nectar guide into the flower.
- The insect forces its way and moves in to collect the nectar.
- As the insect moves in, the stigma and anthers brush against the hairy back of the insect. When this happens, some pollen grains from the anther stick to the hairy back of the insect. At the same time, pollen grains on the insect's back (from another flower which the insect had visited earlier) are transferred to the sticky stigma.
- Although the flower is well-adapted to insect-pollination, self-pollination can still occur.

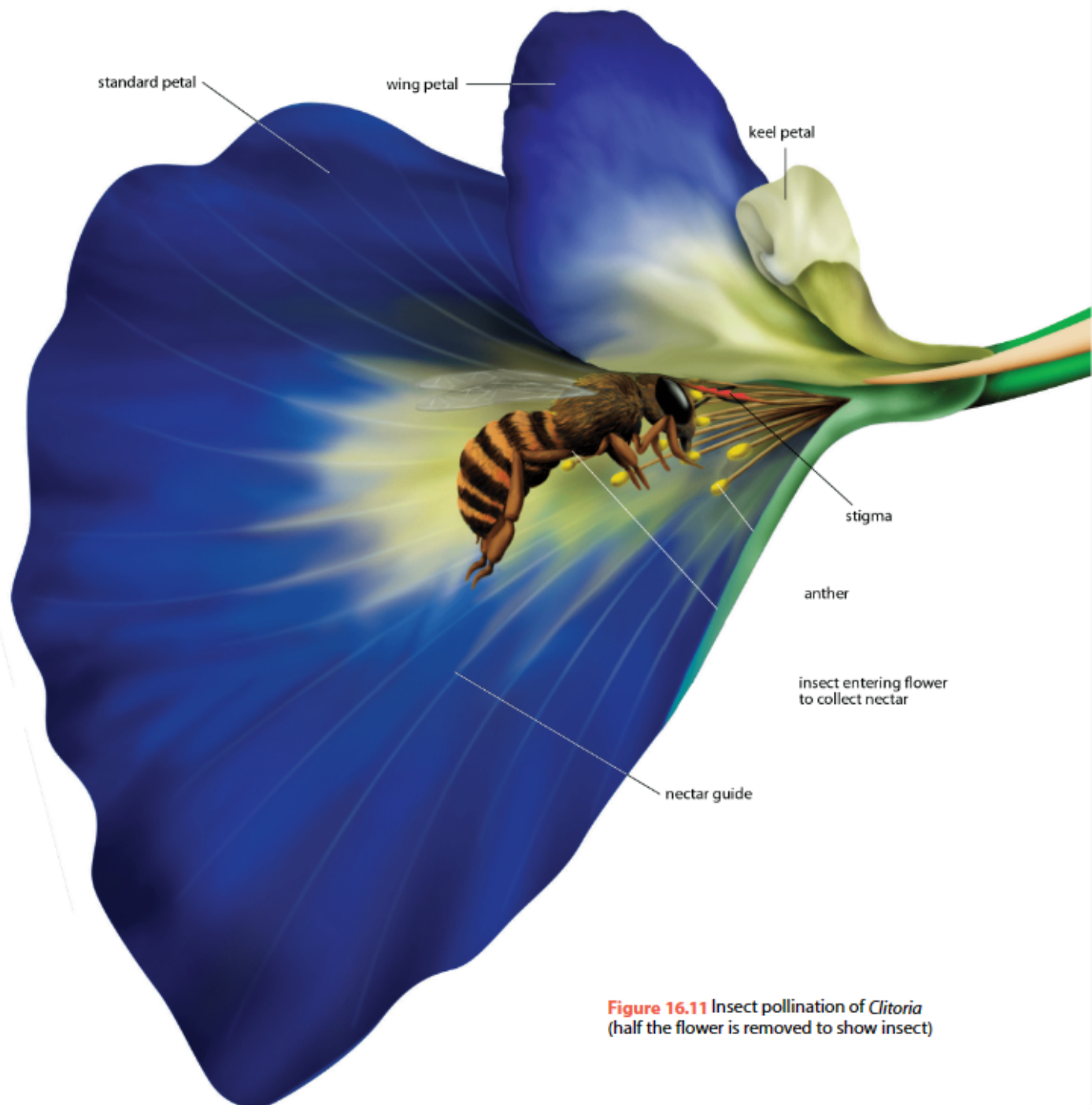


Figure 16.11 Insect pollination of *Clitoria* (half the flower is removed to show insect)

What Are the Structural Adaptations of a Wind-pollinated Flower?

Grasses are good examples of plants with wind-pollinated flowers.

- Grass flowers are usually small and grouped in inflorescences which are dull-coloured, scentless and without nectar.
- Grass flowers are usually enclosed and protected by leaf-like structures called bracts or scales (Figure 16.12).

Structure of *Ischaemum muticum* Flower

Figure 16.12 shows the grass flower of *Ischaemum muticum*, which is specially adapted for cross-pollination by wind.

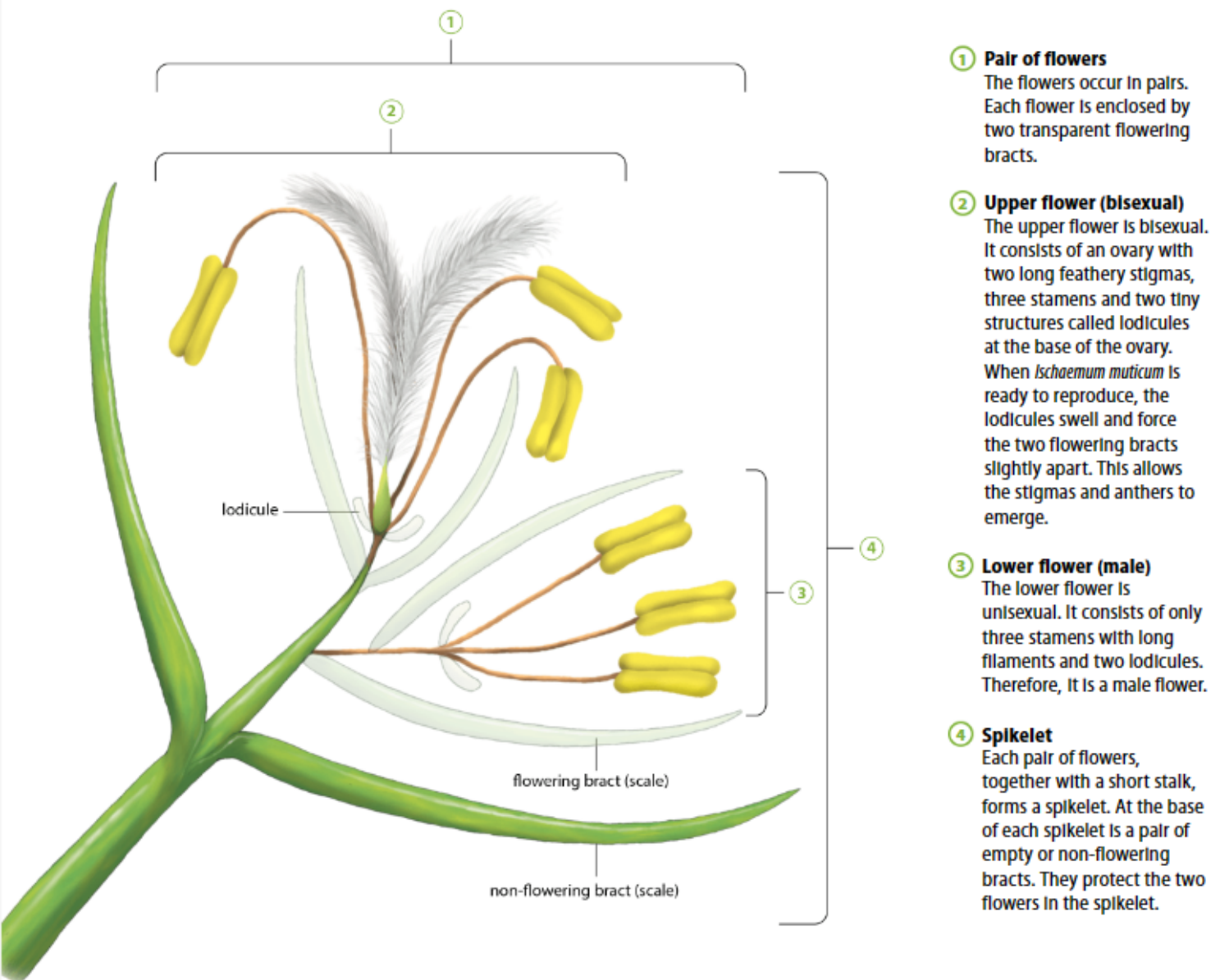


Figure 16.12 Diagrammatic section of a young spikelet of *Ischaemum muticum*. The stamens of the male flower are not fully mature, so they are still enclosed by the flowering bracts. In this way, chances of self-pollination are reduced.

A few pairs of spikelets make up an inflorescence (Figure 16.13).

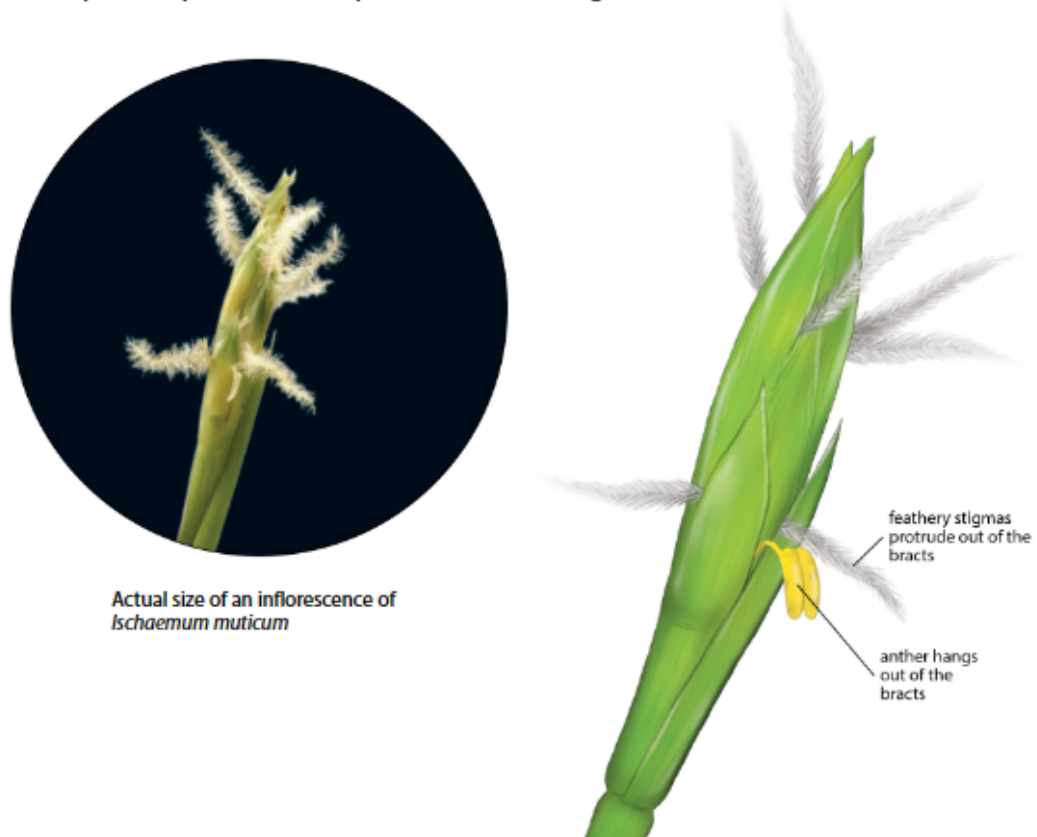


Figure 16.13 An inflorescence of *Ischaemum muticum* with the mature stigmas and anthers hanging out of the bracts

Let's Investigate 16.2

Aim

To examine a wind-pollinated flower under a microscope

Procedure

- 1 First, use dissecting needles to separate the non-flowering bracts of a spikelet to reveal the flowers. Then separate the flowering bracts.
- 2 Examine the external features of the spikelet using a hand lens.
- 3 Examine an anther under the microscope.
- 4 Draw a pollen grain, noting its size and shape.



Link

Practical Workbook
Experiment 16B

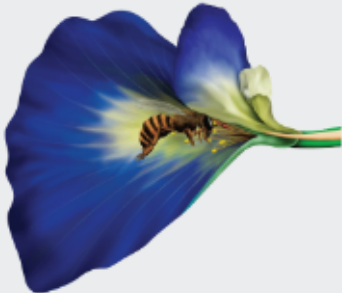
Pollination of *Ischaemum muticum*

- The stamens have long filaments and protruding anthers.
- When the filaments sway in the wind, the dust-like pollen is shaken free and dispersed by the wind.
- The stigmas are large, extended and feathery. Thus, they provide a large surface area to receive any pollen that is floating around in the wind.

How Are Insect-pollinated and Wind-pollinated Flowers Different?

Key differences between insect-pollinated and wind-pollinated flowers are listed in Table 16.3.

Table 16.3 Characteristics of insect-pollinated and wind-pollinated flowers

Feature	Insect-pollinated flowers	Wind-pollinated flowers
	 Example: <i>Clitoria</i> (Blue Pea) flowers	 Example: Grass flowers of <i>Ischaemum muticum</i>
Petals	Flowers are usually large with brightly coloured petals to attract insects.	Flowers are usually small and dull-coloured, without petals.
Nectar	Nectar is present.	Nectar is absent.
Scent	Flowers are fragrant or sweet-smelling.	Flowers are odourless.
Stigmas	Stigmas are usually small, compact and do not protrude out of the flower.	Stigmas are large, feathery and usually protrude out of the flower to provide a large surface area to trap pollen.
Stamens	Stamens are not pendulous and usually do not protrude out of the flower.	Stamens have long pendulous filaments and protruding anthers. Pollen grains are hence easily shaken out from the anthers.
Pollen	Pollen is fairly abundant. Pollen grains are usually larger with rough surfaces so that they can readily cling onto the body of insects.	Pollen is more abundant. Pollen grains have smooth surfaces and are tiny and light so that they are easily blown about by the wind.
Nectar guide	Nectar guide may be present on the petals to guide insects towards the nectar.	Nectar guide absent.



Disciplinary Idea

Structure and Function

Insect-pollinated and wind-pollinated flowers have specific structural features that facilitate the transfer of pollen grains.



Word Alert

Pendulous: hanging loosely and able to swing from side to side like a pendulum

Figure 16.14 shows three people discussing the types of pollination. Comment on their views. Explain why they are correct or incorrect.



Figure 16.14 Three people are discussing the types of pollination. Comment on their views.



Link

Theory Workbook
Worksheet 16B

Let's Practise 16.2

- 1 Explain why self-pollination can occur in a *Clitoria* plant.
- 2 (a) Why is cross-pollination advantageous to plants?
(b) Indicate some of the ways in which cross-pollination may be ensured.
- 3 (a) Describe the pollination of a named insect-pollinated flower.
(b) In what ways is this flower different from a flower adapted for wind-pollination?



16.3 What Happens After Pollination?

Learning Outcome

- Outline the growth of the pollen tube and its entry into the ovule followed by fertilisation.

Have you ever looked at the bottom of fruits such as apples, pears or cucumbers? Did you notice a little structure that looks like the remains of a flower? You see that because fruits come from fertilised flowers! How do flowers become fruits?

The Fertilisation Process

Figure 16.15 shows the process of fertilisation in a generalised flower containing one ovule.

- After pollination, the pollen grain *germinates* after it comes into contact with the stigma. In response to the sugary fluid secreted by the mature stigma.
- A **pollen tube** grows out from each pollen grain. The male gamete enters the pollen tube.
- As the pollen tube grows, it secretes enzymes to digest the surrounding tissue of the stigma and style. Thus, the pollen tube grows down the style into the ovary.
- The pollen tube enters the ovule through an opening in the ovule wall called the **micropyle**.
- Within the ovule, the tip of the pollen tube absorbs sap and bursts, releasing the male gamete.
- The nucleus of the male gamete fuses with the nucleus of the ovum to form the zygote. This is **fertilisation**.
- After fertilisation, the ovary develops into the fruit and the ovule develops into the seed.

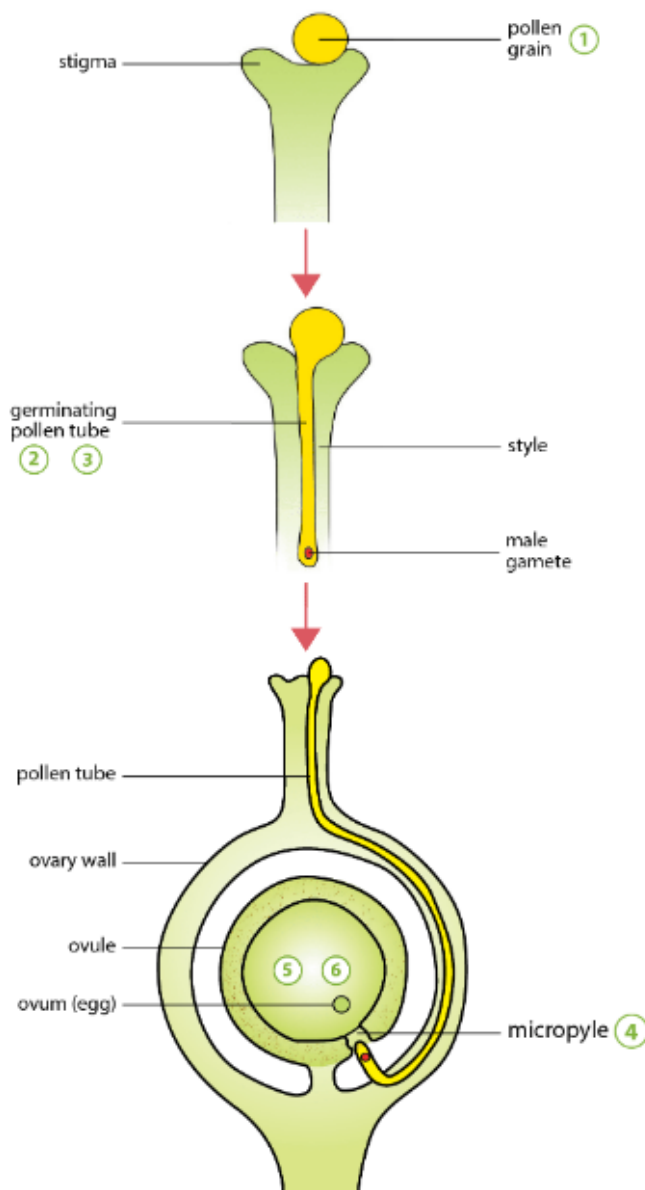


Figure 16.15 Fertilisation in a generalised flower containing only one ovule. Note that the side of the carpel is cut off to show the ovule.

Post-fertilisation Changes

After fertilisation, the following changes take place in the flower:

- The ovary becomes the fruit (Figure 16.16 (top)).
- The ovule becomes the seed (Figure 16.16 (bottom)).
- The zygote becomes the embryo. The embryo consists of the embryonic shoot, the embryonic root and the cotyledons (Figure 16.17).
- The petals, the style and stigma, and the anthers wither and drop off.



Figure 16.16 Developing avocado fruit (top) and avocado seed inside the fruit (bottom)

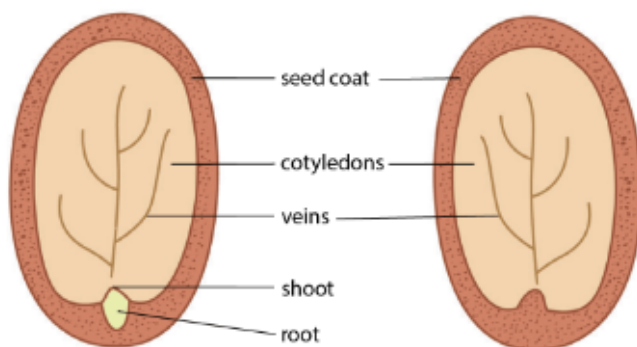


Figure 16.17 Seed cut open and separated into two halves



Cool Career

Horticulturist

Singapore can be proud to be known as a garden city. With her world-famous Singapore Botanic Gardens, Gardens by the Bay and Jewel, horticulturists are needed to maintain the flora in gardens found in those places.

Horticulturists ensure the healthy growth of plants. They select the kinds of plants that are suitable to be grown in certain areas. Sometimes, they also design floral landscapes to create attractive displays for visitors to the gardens. This type of work requires a strong passion in working with plants, understanding of plant life and a lot of creativity.



Figure 16.18 Horticulturist working with plants



Link

Theory Workbook

Worksheet 16C

Let's Assess

Let's Reflect

Let's Practise 16.3

- 1 What will trigger a pollen grain to germinate?
- 2 How does the male gamete find its way to the ovule?
- 3 What do the following parts of a flower develop into after fertilisation?
 - (a) ovary
 - (b) ovule

Let's Map It

Reproduction in Plants

Parts of a flower

- Flower stalk
- Receptacle
- Sepals
- Petals
- Stamens
 - Each consists of a filament and an anther
 - Produce pollen grains, which contain the male gametes
- Carpel (pistil)
 - Consists of stigma, style, ovary and ovule
 - Each ovule contains one ovum (female gamete)

involves male and female gametes brought together by

Pollination

Self-pollination

The transfer of pollen grains from the anther to the stigma of the same flower or of a different flower on the same plant

Cross-pollination

The transfer of pollen grains from one plant to the stigma of a flower in another plant of the same species

by

Insects

e.g.

Clitoria

Wind

e.g.

Ischaemum muticum

may lead to

Fertilisation

- Nucleus of a male gamete fuses with the nucleus of a female gamete to form a zygote

Let's Review

Section A: Multiple-choice Questions

1 Figure 16.19 shows a flower.

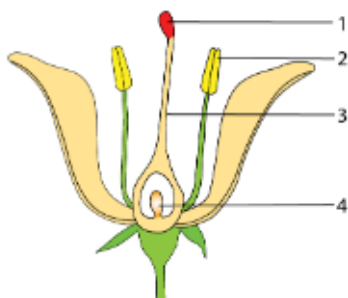


Figure 16.19

In which structures are haploid nuclei formed by meiosis?

- ☐ A 1 and 2 ☐ B 1 and 4
☐ C 2 and 4 ☐ D 3 and 4

2 Wind-pollinated flowers have _____

- ☐ A a compact stigma and light pollen
☐ B a compact stigma and large pollen
☐ C a feathery stigma and light pollen
☐ D a feathery stigma and large pollen

3 An investigation was carried out using flowers on three different plants of the same species.

Plant 1 – The anthers were cut off and the flowers were left exposed to the air.

Plant 2 – The anthers were left intact and a paper bag was wrapped around each flower.

Plant 3 – The anthers were removed and a paper bag was wrapped around each flower.

All the flowers later opened normally, but only those on plant 1 produced seeds. The result shows that in this species of plants,

- ☐ A only cross-pollination can take place.
☐ B only insect-pollination can take place.
☐ C only wind-pollination can take place.
☐ D both self- and cross-pollination can take place.

4 After fertilisation, which structure develops into the seed of a plant?

- ☐ A the carpel
☐ B the ovule
☐ C the receptacle
☐ D the ovum

5 Which of the following is the male part of a flower?

- ☐ A petal
☐ B sepal
☐ C anther
☐ D stigma

Section B: Structured Question

1 Figure 16.20 shows a diagram of a flower.



Figure 16.20

- (a) Label the stigma, anther and filament on the diagram.
 (b) Is the flower pollinated by wind or insects?
 (c) For each structure you have labelled, describe how it is adapted to the method of pollination you have mentioned in (b).

Section C: Free-response Questions

- 1 Distinguish between pollination and fertilisation.
 2 Distinguish between self-pollination and cross-pollination.

CHAPTER

17 Reproduction in Humans

What You Will Learn



- What makes up the human reproductive system?
- What is the menstrual cycle?
- What happens during and after fertilisation?
- What is HIV/AIDS?

We learn to breathe only after we have left our mothers' wombs at birth. We do not breathe while we are inside the womb. As fetuses, we still need to obtain oxygen for tissue respiration and expel carbon dioxide and other toxic substances from our bodies. How is this possible without breathing?

This chapter explores the wonder of how the human life develops from just one cell to the entire living, breathing organism.



17.1 What Makes Up the Human Reproductive System?

Learning Outcomes

- Identify the male reproductive system and state the functions of: testes, scrotum, sperm ducts, prostate gland, urethra and penis.
- Identify the female reproductive system and state the functions of: ovaries, oviducts, uterus, cervix and vagina.



Link

Recall from Chapter 15 about sexual reproduction and meiosis.

Recall what you have learnt about the urinary system in Chapter 8.

You would have noticed that children produced from the same parents may not look or behave alike. Like many flowering plants, humans reproduce through sexual reproduction. This involves the fusion of two gametes from two different parents. The male gamete and the female gamete fuse to form a zygote. Gametes are genetically dissimilar as they are produced by meiosis. The gametes are produced in the reproductive systems.

In this chapter you will study how sexual reproduction takes place in humans.

The Male Reproductive System

The various parts of the human male reproductive system (labelled 1 to 6) are shown in Figure 17.1. Note that the reproductive system is closely associated with the urinary system in males. (The urinary system is responsible for the production and removal of urine. It is made up of the kidneys, ureter, urinary bladder and the urethra.)

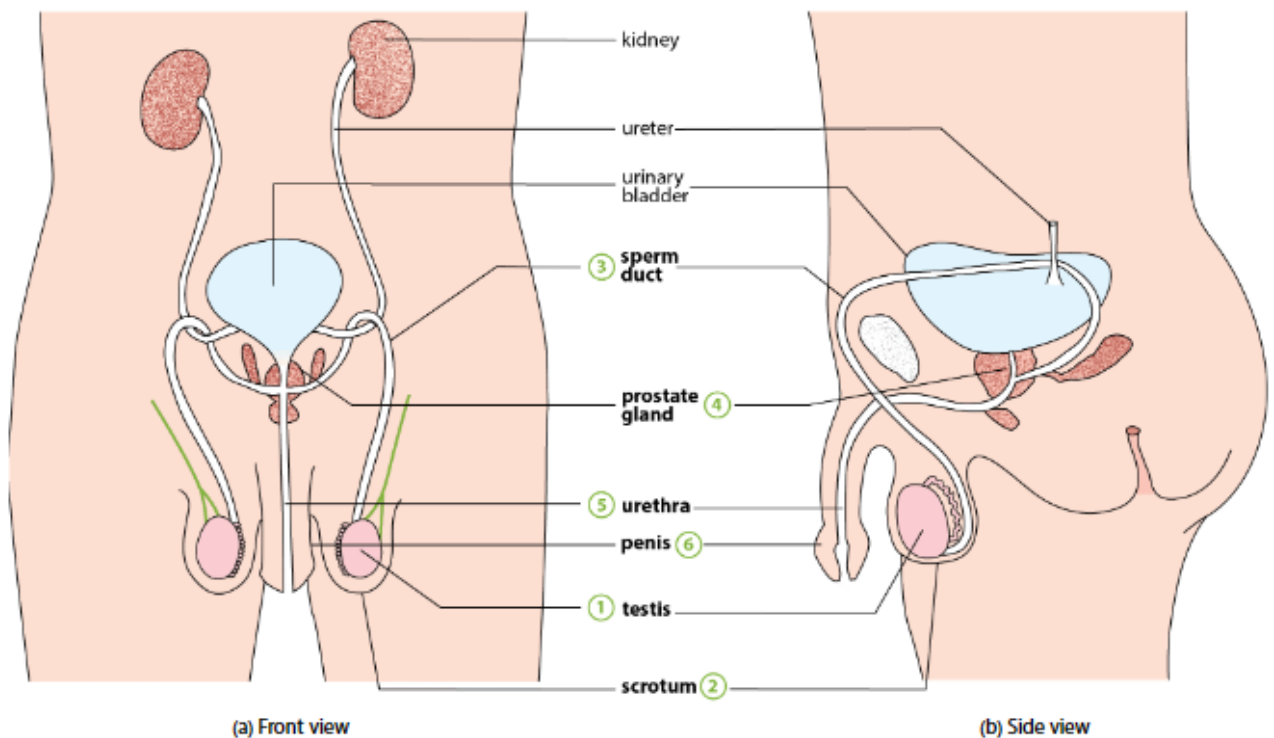


Figure 17.1 Structure of the male reproductive system

1 Testis

- There are two **testes**. Each testis produces **sperm**. Each testis also produces male sex hormones such as testosterone.
- The male hormones are responsible for the development and maintenance of the secondary sexual characteristics in males.

2 Scrotum

- The testes lie between the thighs. Both testes lie in a pouch-like sac called the **scrotum**.
- The scrotum is outside the main body cavity. Thus, it is at a slightly lower temperature than body temperature. The lower temperature is essential for sperm to develop properly.

3 Sperm duct

- Each **sperm duct** loops over a **ureter** and then opens into the urethra.
- After sperm are released from a testis, they travel through a sperm duct.

4 Prostate gland and its secretions

- The **prostate gland** is at the base of the urinary bladder, where the two sperm ducts join the urethra.
- The prostate gland secretes a fluid which mixes with the sperm. This fluid contains nutrients and enzymes which nourish the sperm and stimulate them to swim actively. The mixture of fluid and sperm is called **semen**.

5 Urethra

- The **urethra** is a tube which passes from the bladder through the centre of the penis to the outside of the body.
- Both semen and urine pass out of the body through the urethra.

6 Penis

- The **penis** is an **erectile** organ.
- The penis enters the vagina of a woman during sexual intercourse to deposit semen, containing sperm.



Disciplinary Idea

System

The male reproductive system consists of various parts that work together to facilitate reproduction.



Helpful Note

Semen and urine do not pass through the urethra at the same time. A circular band of muscle called the sphincter muscle at the base of the urinary bladder can be controlled to prevent urine from coming out of the bladder during **ejaculation**.



Word Alert

Sperm: used for the singular and plural forms, and the collective noun
Erectile: able to become rigid and upright
Ejaculation: release of semen containing sperm



Disciplinary Idea

Structure and Function

The structure of the sperm is highly adapted for its functions. It is motile to enable fertilisation to take place.

Figure 17.2 shows the structure of a sperm.

1 Sperm

- The **sperm** is the male gamete.
- Numerous sperm are produced throughout the life of a male human after he has become physically mature. A sperm is about 60 μm long.

2 Middle piece

- The middle piece contains numerous mitochondria.
- The mitochondria provide energy for the sperm to swim towards the egg.

3 Tail (flagellum)

- The beating movement of the tail or flagellum enables the sperm to swim towards the egg.
- The tail allows the sperm to be motile (able to move).

2 Head

- The head is about 2.5 μm wide.
- It contains a large nucleus with small amount of cytoplasm. The nucleus carries a haploid set of chromosomes.

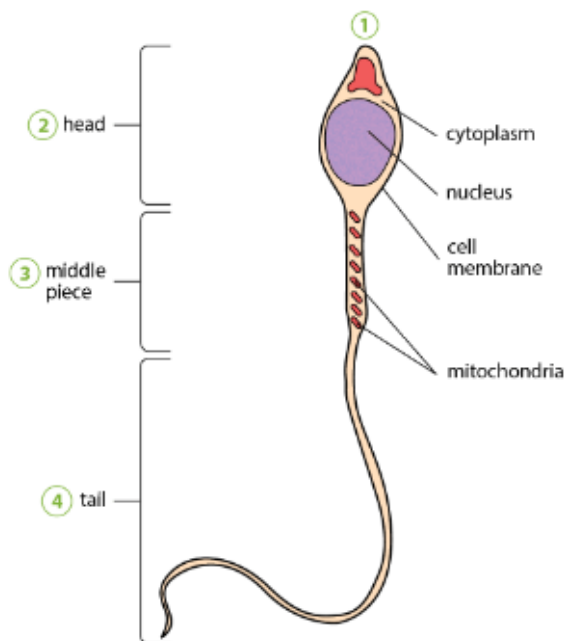


Figure 17.2 Sperm

The sperm travels from the testis and out of the penis as follows:

Testis → Sperm duct → Urethra
 ↓
 Outside the body



Link

Recall what you have learnt about the urinary system in Chapter 8.

The Female Reproductive System

The various parts of the human female reproductive system (labelled 1 to 5) are shown in Figure 17.3. Note that the reproductive system is closely associated with the urinary system in females.

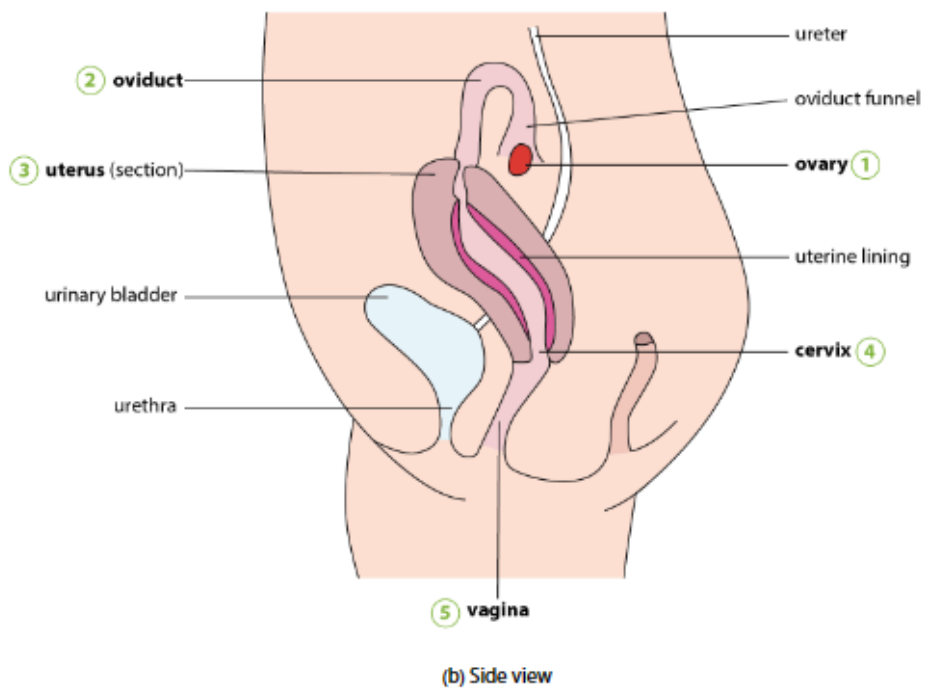
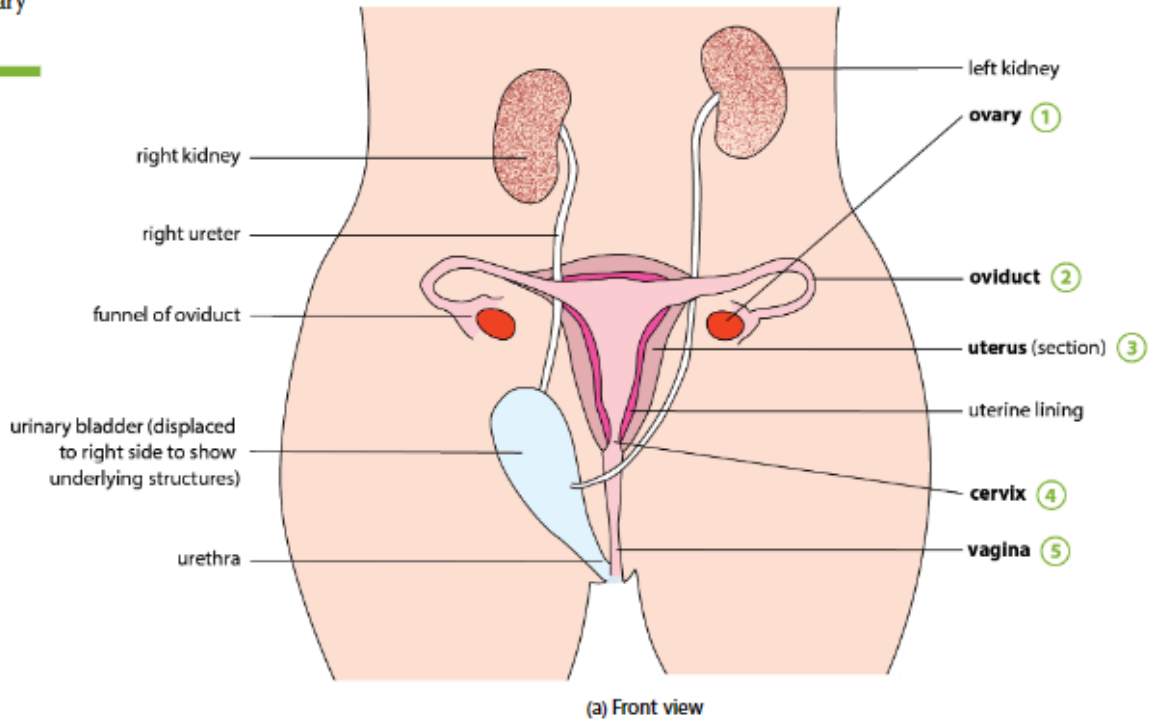


Figure 17.3 Structure of the female reproductive system

1 Ovary

- The two **ovaries** produce **ova (eggs)**.
- Each ovary also produces hormones such as oestrogen and progesterone.
- The female sex hormones are responsible for the development and maintenance of the secondary sexual characteristics in females.
- When the eggs become mature, they are released from the ovaries.

2 Oviduct

- Each ovary releases mature eggs into an **oviduct**.
- Each oviduct is a narrow muscular tube leading from the ovary to the uterus. It has a funnel-like opening lying close to the ovary. This makes it easier for the egg to enter the oviduct.
- The egg is usually fertilised in the oviduct.
- The inner surface of the oviduct is lined with cilia. The movement of the cilia helps to move the egg along the oviduct.

3 Uterus

- The **uterus** (plural: **uteri**) or **womb** is where the **fetus** (sometimes spelled **foetus**) or unborn baby develops during pregnancy.
- The uterus is shaped like an upside-down pear. It has elastic muscular walls. The smooth muscle tissue in the walls of the uterus contract to push the fetus out during birth.
- The soft, smooth inner lining of the uterus is called the **uterine lining**. It is where the **embryo** is implanted.

4 Cervix

- The **cervix** is the ring of muscles at the lower portion of the uterus where it joins the vagina.
- The opening of the cervix allows menstrual blood to flow out into the vagina during menstruation.

5 Vagina

- The **vagina** or **birth canal** leads from the cervix to the outside.
- Semen is deposited in the vagina during mating or sexual intercourse.



Word Alert

Embryo: the ball of cells that is formed when the zygote or fertilised egg divides



Disciplinary Idea

System

The female reproductive system consists of various parts that work together to facilitate reproduction.

Figure 17.4 shows the structure of the ovum or egg.

Ovum

- The **ovum** (plural: **ova**) or egg is the female gamete. A female is born with all the potential eggs she will ever have. At birth, about 70 000 potential egg cells are already present in the ovaries. However, only about 500 will ever become mature within the two ovaries. Usually only one mature egg is released every month from the time a female becomes physically mature until about 45–55 years of age.
- The egg is spherical and about 120 μm to 150 μm wide.
- The egg:
 - has abundant cytoplasm which may contain a small amount of yolk
 - is surrounded by a cell membrane which in turn is surrounded by an outer membrane (or jelly coat); the outer membrane changes during fertilisation to prevent other sperm from entering the egg

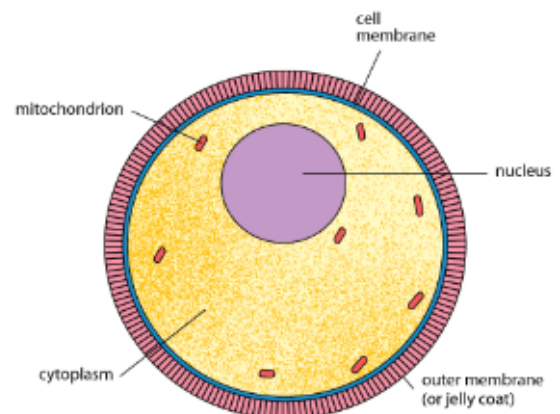


Figure 17.4 Ovum or egg

How Are Male and Female Gametes Different?

You have seen how the male and female gametes are adapted for their functions. The gametes differ in structure, motility and number (Table 17.1).

Table 17.1 Male and female gametes

Feature	Male Gamete	Female Gamete
Structure	- Has a head, a middle piece and a tail - Nucleus contains either X or Y chromosome - About 60 μm long with a diameter of 2.5 μm for the head	- Spherical in shape - Nucleus has one X chromosome - Diameter of 120 μm to 150 μm
Motility	Has a tail that enables it to swim towards the oviduct	Passive movement of egg along the oviduct is due to the movement of cilia along the oviduct and peristalsis of the oviduct wall.
Numbers	A large number of sperm is released per ejaculation.	Only one egg is released per month. Both ovaries together produce about 500 mature eggs.



Helpful Note

Sperm are small so that many can be released at the same time. The ovum is much larger with abundant cytoplasm to store nutrients for the early development of the embryo.

Let's Practise 17.1

- Why is it important for the testes to be outside the body cavity?
- Figure 17.5 shows a side view of some structures in the lower abdomen of a woman.
 - Name the parts labelled A to E.
 - Using the letters A to E, state the part where:
 - sperm are deposited during sexual intercourse
 - fertilisation occurs
 - the fetus develops
 - eggs are produced
 - female sex hormones are produced
- State the differences between the sperm and the egg in terms of:
 - structure
 - motility
 - numbers released per ejaculation/ovulation

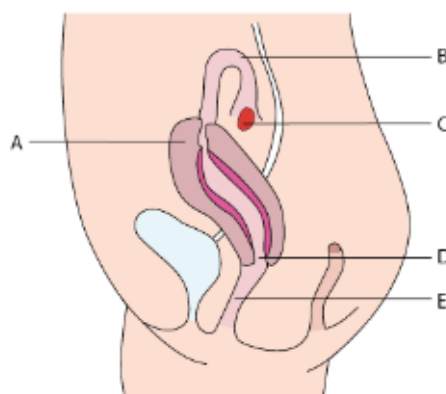


Figure 17.5 Side view of some structures in the lower abdomen of a woman



Link

Theory Workbook
Worksheet 17A

17.2 What Is the Menstrual Cycle?

Learning Outcomes

- Outline the menstrual cycle with reference to the alternation of menstruation and ovulation, and the natural variation in its length.
- Outline the fertile and infertile phases of the menstrual cycle with reference to the effects of progesterone and oestrogen.

For a female, the first sign of puberty is usually the monthly discharge of blood or menses from the uterus via the vagina. This is called **menstruation**. The menstrual period or time of menstruating usually lasts for about five days. However, the length of the menstrual period and the amount of blood lost vary from female to female.

Menstruation is part of a cycle of events that takes place in the female reproductive organs every month. This cycle of events is called the **menstrual cycle**. The average menstrual cycle for an adult female is 28 days. However, menstrual cycles ranging from about 21 to 33 days are not abnormal. There is natural variation in the length of the menstrual cycle. Stress, tiredness, illness, unbalanced diet or malnutrition may alter or stop the menstrual cycle and change the interval between periods.

As a female ages, the ovaries will eventually stop releasing eggs and the menstrual cycle will stop. This is called **menopause**. Menopause usually takes place between 45 and 55 years of age.



Helpful Note

Puberty is the stage of human growth and development in which a person becomes physically mature. It usually begins at the age of about 11 for females and 14 for males.

What Are the Stages in the Menstrual Cycle?

Figure 17.6 shows the changes that take place during the menstrual cycle.

- 1 Menstruation**
 - The uterine lining and unfertilised egg break down and are shed with some blood.
- 2 After menstruation**
 - The ovary produces a hormone called **oestrogen**.
 - Oestrogen causes the uterine lining to repair and thicken.
 - High oestrogen concentration leads to ovulation.
- 3 Ovulation**
 - On the 14th day, an ovary releases an egg into the oviduct through a process known as **ovulation**.
 - The two ovaries take turns to release an egg.
- 4 After ovulation**
 - The ovary produces a hormone called **progesterone**.
 - Functions of progesterone:
 - prevents ovulation and further development of eggs
 - causes the uterine lining to thicken further, preparing it for the implantation and growth of the embryo
 - Oestrogen production decreases.
 - If no fertilisation occurs, progesterone production decreases.
 - The uterine lining breaks down and the whole cycle repeats.

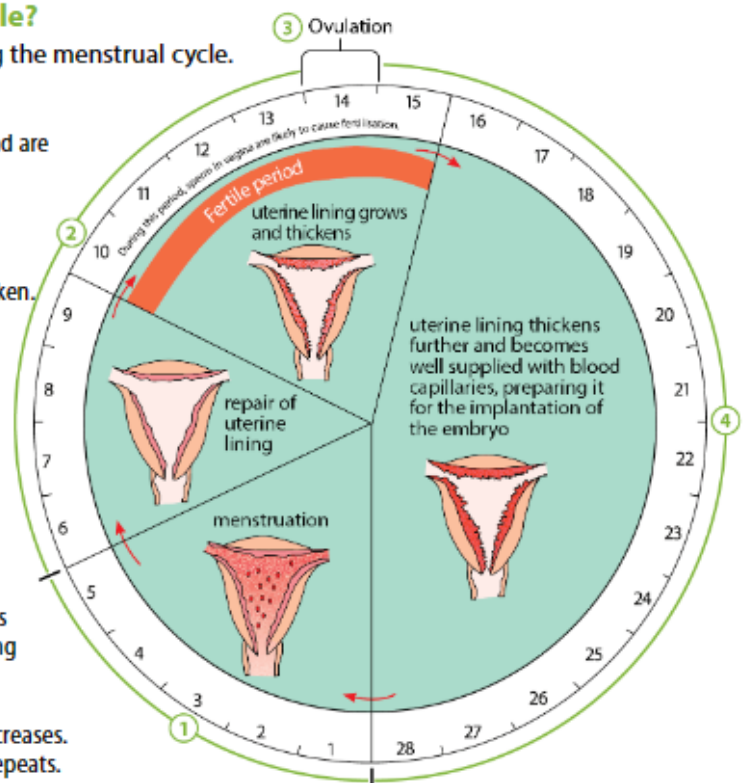


Figure 17.6 Summary of changes during a menstrual cycle of 28 days, assuming ovulation occurs on day 14

The changes relating to the hormones and uterine lining during the menstrual cycle are shown in Figure 17.7.

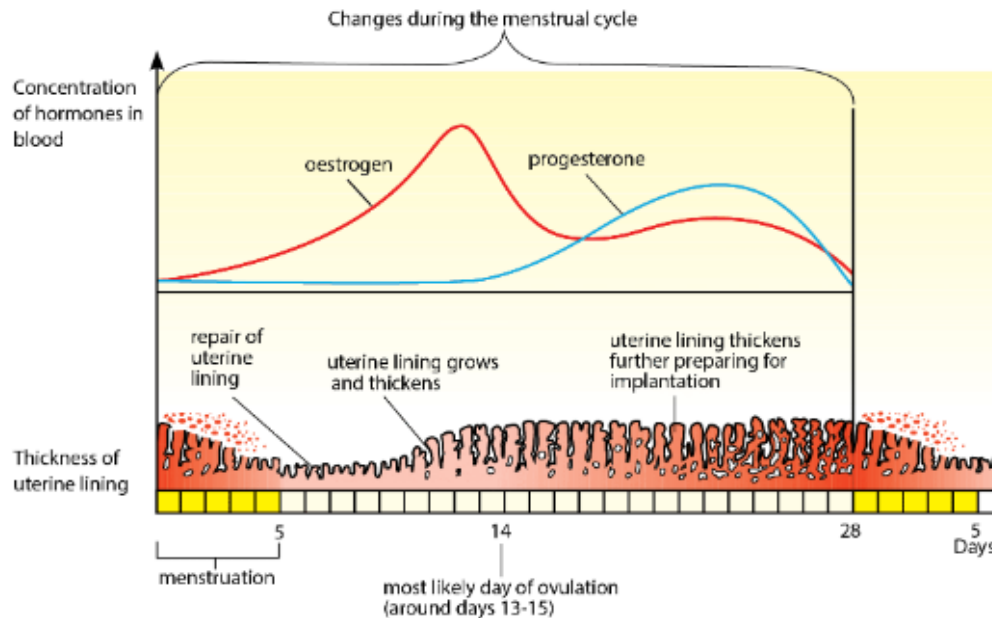


Figure 17.7 The human menstrual cycle



Disciplinary Idea

Homeostasis, Coordination and Response

The functions of the human reproductive system are regulated by hormones (e.g. menstrual cycle is regulated by oestrogen and progesterone).

What Happens If No Fertilisation Occurs?

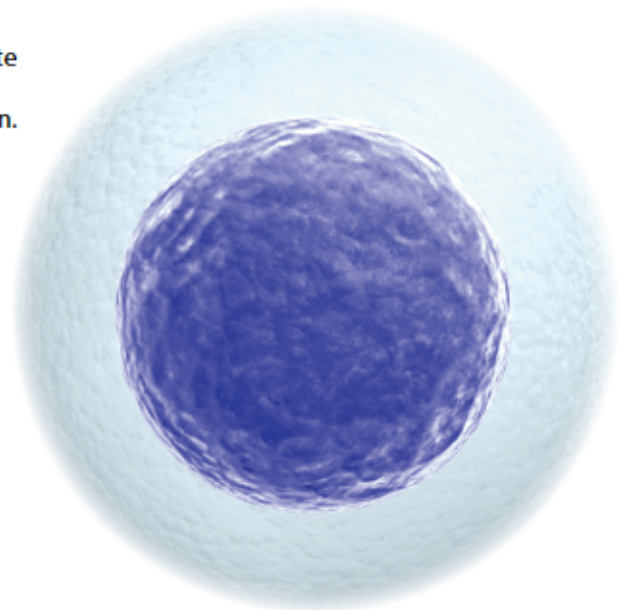
When fertilisation does not occur:

- The egg breaks down.
- The blood progesterone level decreases.
- On the 28th day, without progesterone, the uterine lining begins to break down. Menstruation begins again.
- The whole cycle repeats.

What Happens If Fertilisation Occurs?

When fertilisation occurs:

- The fertilised egg becomes a zygote. The zygote develops into an embryo.
- The ovary secretes progesterone and oestrogen. This causes the maintenance and thickening of uterine lining for the implantation of the embryo.
- The embryo embeds itself in the uterine lining until a structure called the placenta is formed.
- The ovary continues to secrete progesterone and oestrogen until the placenta is able to take over the production of the two hormones.



When Are the Fertile and Infertile Periods of the Menstrual Cycle?

- An egg can survive in the oviduct for up to 24 hours. If ovulation occurs on the 14th day in a 28-day menstrual cycle, the egg can survive from day 14 to day 15.
- Sperm can survive in the female reproductive system for about three to five days. This means that sperm deposited into the vagina around day 10 can fertilise the egg and bring about pregnancy.
- Hence, fertilisation is possible if sexual intercourse occurs during day 10 to day 15 of the menstrual cycle. This period is known as the **fertile period**.
- The rest of the days make up the **infertile periods** of the menstrual cycle. (Note that we are assuming that the menstrual period is highly regular. You have learnt earlier that there are various factors that may affect and alter the menstrual cycle.)

Now that you have learnt about the menstrual cycle, examine the conversation between the three women in Figure 17.8. Do you agree with each of their views? Why or why not?

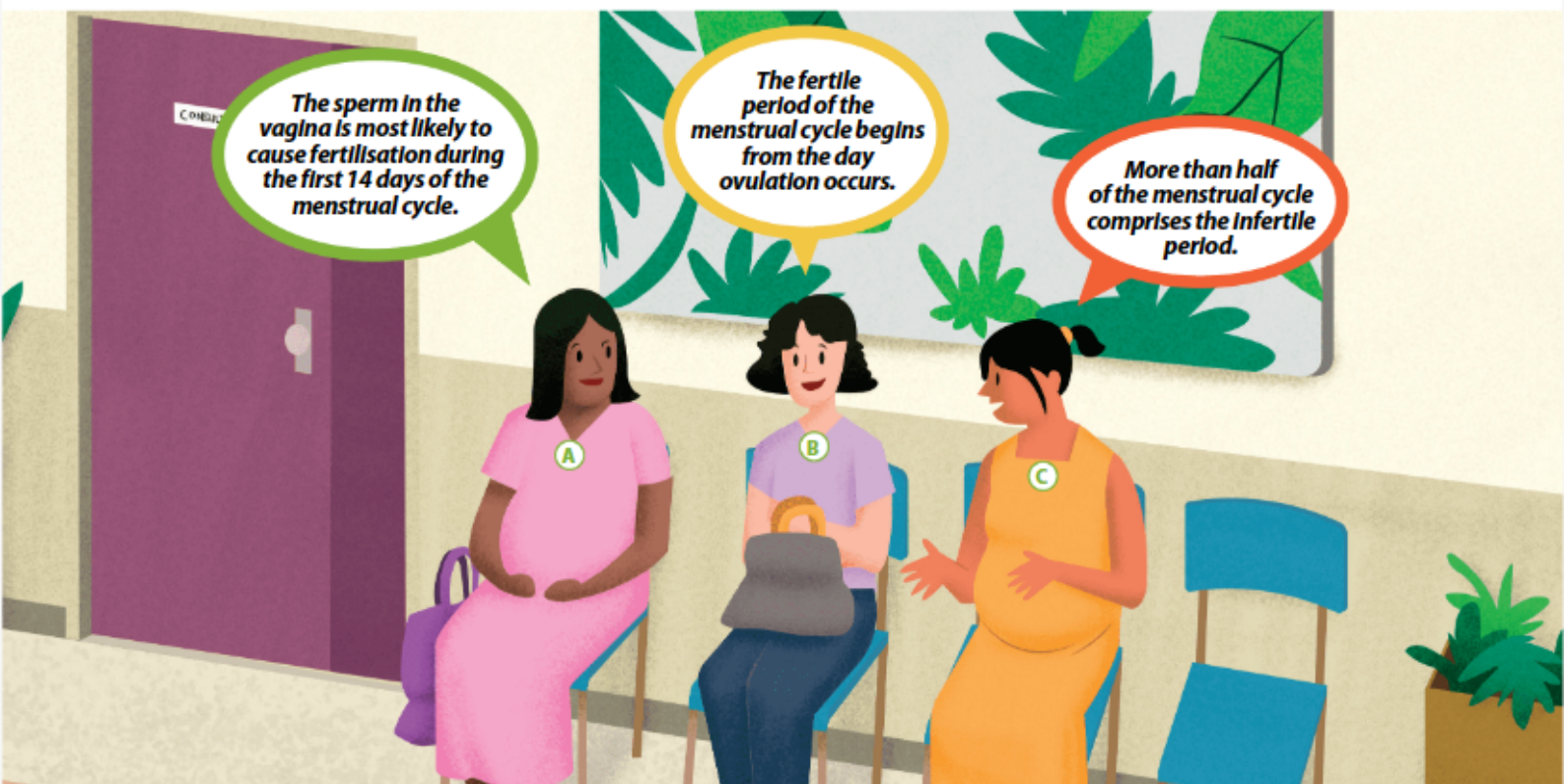


Figure 17.8 Three women are having a conversation on the menstrual cycle. Give your views on their statements.

Let's Practise 17.2

- Study Figure 17.7 on the previous page.
 - What are the effects of oestrogen and progesterone on the uterine lining?
 - When is the fertile period?
 - What happens to the uterine lining during the first five days?



Link

Theory Workbook
Worksheet 17B

17.3 What Happens During and After Fertilisation?

Learning Outcomes

- Describe fertilisation and early development of the zygote simply in terms of the formation of a ball of cells which becomes implanted in the wall of the uterus.
- State the functions of the amniotic sac and the amniotic fluid.
- Describe the function of the placenta and umbilical cord in relation to exchange of dissolved nutrients, gases and excretory products.

Identical twins are always either both male or female and they look very much alike. However, some twins are not identical. They can be both male, both female, or one male and one female. What happens during human reproduction to give these different results?

Mating or Sexual Intercourse

When a male becomes sexually stimulated or aroused, blood is pumped into the penis faster than it can return to the bloodstream via the veins. Hence, the blood fills the spaces in the spongy tissues of the penis. This causes the penis to become stiff and erect to allow it to enter the vagina of a female. This is known as mating, copulation or sexual intercourse.

Semen containing sperm is ejaculated into the vagina, along with a liquid made by the prostate gland. The sperm are able to swim up the oviducts of the female in this liquid. The chemicals in this liquid also make the sperm tails beat to propel the sperm along the oviducts. If a sperm meets an egg in the oviduct, fertilisation may occur. Millions of sperm are released into the vagina during one ejaculation. Only one of these will fertilise the egg.



Helpful Note

Identical twins are produced from one fertilised egg or zygote that divides into two. They have the same genes and are therefore identical.

When two eggs are released into the oviduct at about the same time, the two eggs can be fertilised by two different sperm. The two zygotes formed do not contain the same genetic material. Thus, the twins formed are not identical.

How Does Fertilisation Occur?

- **Fertilisation** is the process by which the nucleus of the male gamete fuses with the nucleus of the female gamete to produce a zygote.

The process of fertilisation is shown in Figure 17.9.

- ① Only one sperm nucleus enters the egg. The sperm nucleus fuses with the egg nucleus, and a fertilised egg or zygote is formed. This process is known as *fertilisation*.
- ② As soon as the sperm has entered the egg, no other sperm can enter. The remaining sperm, which do not fertilise the egg, eventually die.

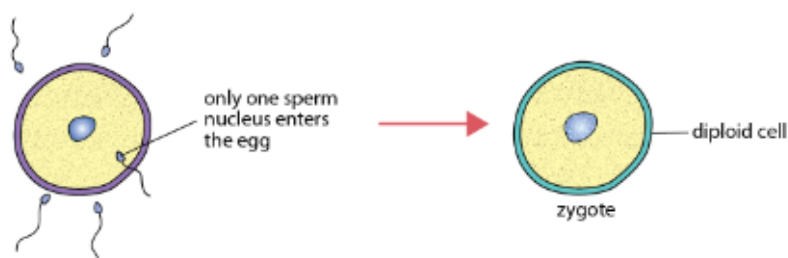


Figure 17.9 Fertilisation

How Does the Embryo Develop?

Figures 17.10 and 17.11 show how the embryo develops after fertilisation.

Implantation

- ① The cilia lining the inner surface of the oviduct sweep the fertilised egg or zygote along the oviduct. Peristaltic movements in the wall of the oviduct also help move the zygote to the uterus.
- ② The zygote divides by mitosis to form a ball of cells called the **embryo**. The energy needed for this early stage of cell division is provided by the nutrients stored in the egg. It takes about five days for the embryo to reach the uterus. The embryo may float freely in the uterus for about two days.
- ③ Eventually, the embryo sinks into or becomes embedded in the uterine lining. This is called **implantation**. Implantation usually occurs about seven days after fertilisation.

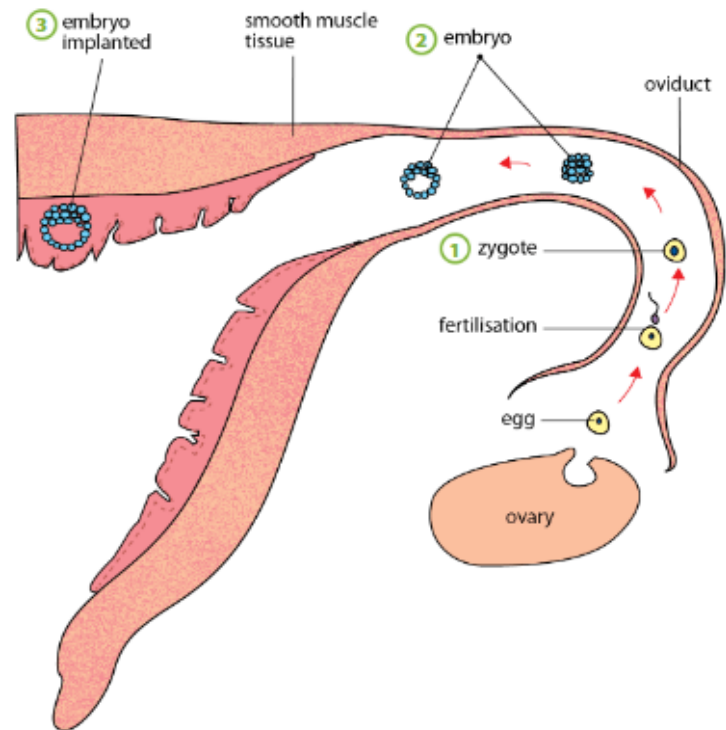


Figure 17.10 Early stages of the development of the embryo

Development of the Placenta

- ④ Soon after implantation, finger-like projections called villi begin to grow from the embryo into the uterine lining. They contain the blood capillaries of the embryo.
- ⑤ The villi and the uterine lining, in which the villi are embedded, make up the **placenta**.
- ⑥ A tube known as the **umbilical cord** attaches the embryo to the placenta.

Development of the Amniotic Sac

- ⑦ A membrane called the **amniotic sac** or **amnion** begins to develop at about the same time as the placenta.
- ⑧ The amniotic sac encloses the embryo in a fluid-filled space known as the **amniotic cavity**. The fluid in the amniotic cavity is called **amniotic fluid**.
- ⑨ The embryo continues to develop. In humans, about 10 to 12 weeks after fertilisation, all the major organs are formed. From this stage onwards, the embryo is known as a **fetus**.

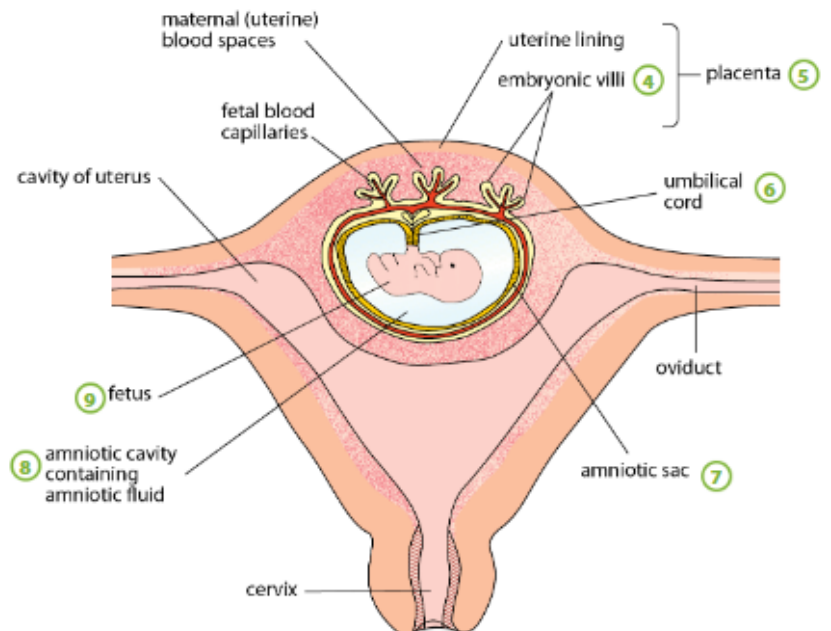


Figure 17.11 Development of the amniotic sac and placenta in the uterus



Word Alert

Maternal: of the mother
Fetal: of the fetus

What Are the Functions of the Placenta?

The placenta has the following functions:

- It allows oxygen and dissolved food substances, such as glucose, amino acids and mineral salts, to diffuse from the **maternal** blood into the **fetal** blood.
- It allows metabolic waste or excretory products, such as urea and carbon dioxide, to diffuse from the fetal blood into the maternal blood.
- It allows protective antibodies to diffuse from the maternal blood into the fetal blood. The antibodies protect the fetus against certain diseases.
- It produces oestrogen and progesterone which maintain the uterine lining in a healthy state during pregnancy.

What Are the Functions of the Umbilical Cord?

The umbilical cord attaches the fetus to the placenta. The umbilical cord (Figure 17.12) contains the blood vessels of the fetus. It contains the following:

- two umbilical arteries that transport deoxygenated blood and metabolic waste products from the fetus to the placenta
- one umbilical vein that transports oxygenated blood and food substances from the placenta to the fetus

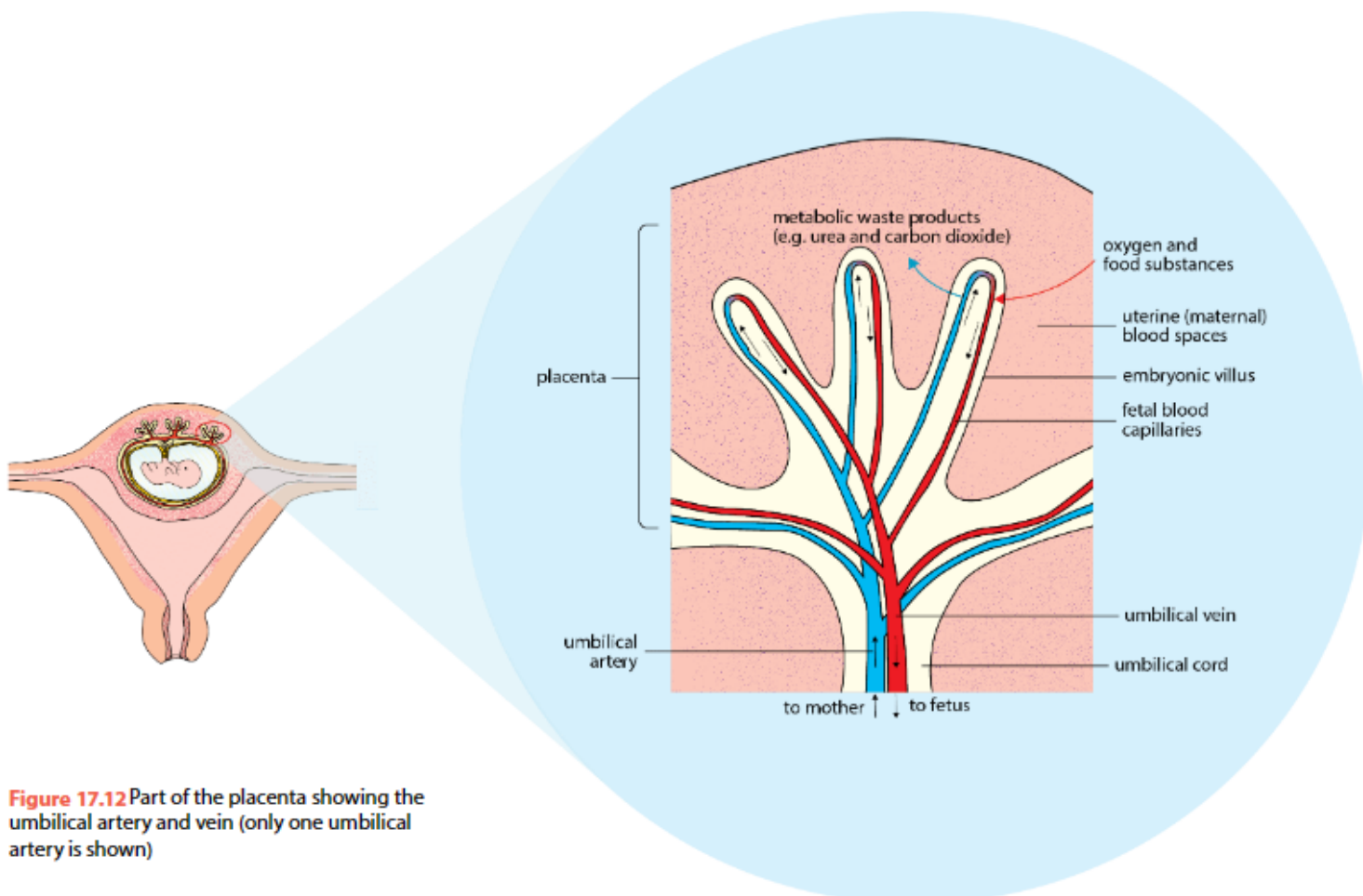


Figure 17.12 Part of the placenta showing the umbilical artery and vein (only one umbilical artery is shown)

What Are the Functions of the Amniotic Fluid?

The amniotic sac encloses the fetus in the amniotic cavity, which contains amniotic fluid. The functions of amniotic fluid are as follows:

- It supports and cushions the fetus before birth. It is a shock absorber. As it cannot be compressed, it protects the fetus against physical injury.
- It allows the fetus a certain degree of movement, which promotes muscular development.
- During birth, it lubricates and reduces friction in the vagina or birth canal.

The fetus continues to grow in the uterus. At the end of nine months of pregnancy, the fetus is fully formed and is ready to be born.

The Fetal Blood System Is Separated from the Maternal Blood System

Figure 17.13 shows a section of the human uterus containing a fetus. The fetal blood capillaries are surrounded by maternal blood spaces. In the placenta, the fetal blood capillaries are separated from the maternal blood system by only a thin layer of tissue. Diffusion of dissolved substances can occur across this layer of tissue.

However, pathogens and toxins that may be present in the maternal bloodstream can pass across the placenta and affect the fetus.

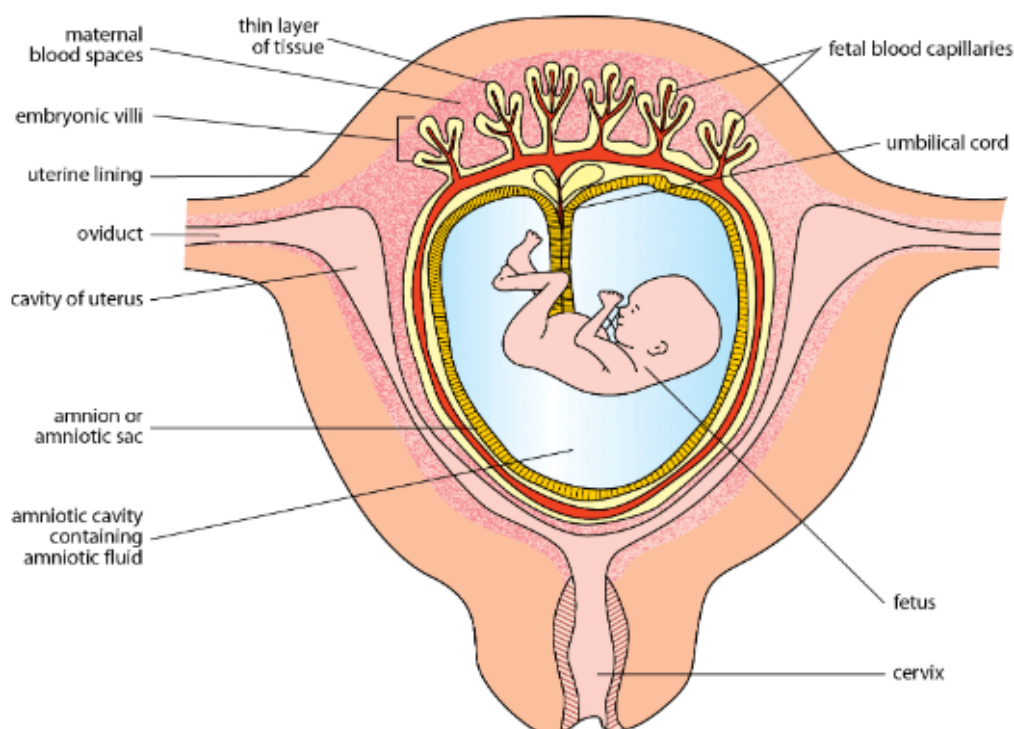


Figure 17.13 Section showing fetus in the uterus



Helpful Note

The period from fertilisation or conception to birth is known as the **gestation** period. This period varies — 38 weeks (or about 9 months) for humans, 1 year and 9 months for elephants, and only 19 days for mice!



Link

Diffusion is how dissolved substances move in water. Remember what you have learnt in Chapter 2.





Link

Antigens on the surface of red blood cells may react with antibodies from a different blood group and cause blood cells to agglutinate. Recall what you have learnt in Chapter 6.

Why Is the Fetal Blood System Not Continuous with the Maternal Blood System?

The fetal blood system is not continuous with the maternal blood system. The two blood systems cannot be continuous because of the following:

- The blood pressure of the mother would kill the fetus as it is much higher than that of the fetus.
- The blood group of the fetus may not be the same as the mother's. If the fetus and the mother have different blood groups and the two blood systems were allowed to mix, antibodies in the mother's blood may cause the fetal blood cells to agglutinate. This would be dangerous to both mother and fetus.
- This prevents potential harmful substances or pathogens from directly entering the fetal bloodstream.



Tech Connect

In March 2021, it was reported that a group of scientists in Israel had placed a mouse embryo in a glass jar to grow. The embryo was able to successfully develop within 12 days. This is about half the time it takes for the embryo to develop in the mother's womb before birth. Within the artificial womb of the glass jar, this embryo developed a beating heart and a head, and limbs were beginning to form. Could this be the future of human reproduction (Figure 17.14)? What ethical issues can you think of if this technology is allowed to be used in human reproduction?



Figure 17.14 Exploring artificial womb technology



Link

Theory Workbook
Worksheet 17C

Let's Practise 17.3

- 1 What is a zygote?
- 2 State the functions of the following:
 - (a) umbilical cord
 - (b) placenta
 - (c) amniotic sac
 - (d) amniotic fluid



17.4 What Is HIV/AIDS?

Learning Outcome

- Discuss the transmission of human immunodeficiency virus (HIV) and methods to reduce transmission.

A disease spread or transmitted through sexual intercourse is called a **sexually transmitted infection (STI)**. STIs can result in irreversible physical damage or even death. They are caused by bacteria or viruses. The bacteria or viruses carried in the bloodstream of the infected person may be transmitted to an uninfected person in the following ways:

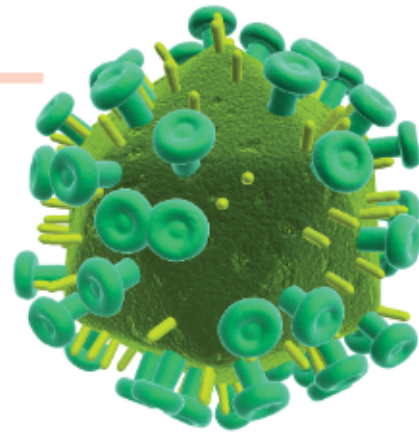
- through semen when it comes into contact with the mucous membrane in the vagina
- through fluid in the vagina when it comes into contact with the mucous membrane of the urethra
- when blood from an infected person gets into the bloodstream of an uninfected person

What Is HIV?

HIV stands for **Human Immunodeficiency Virus**. This virus destroys the body's immune system — the system that protects a person against infection. HIV infection might develop into AIDS in the later stages.

AIDS stands for **Acquired Immune Deficiency Syndrome**. It is the most widely known STI caused by a virus.

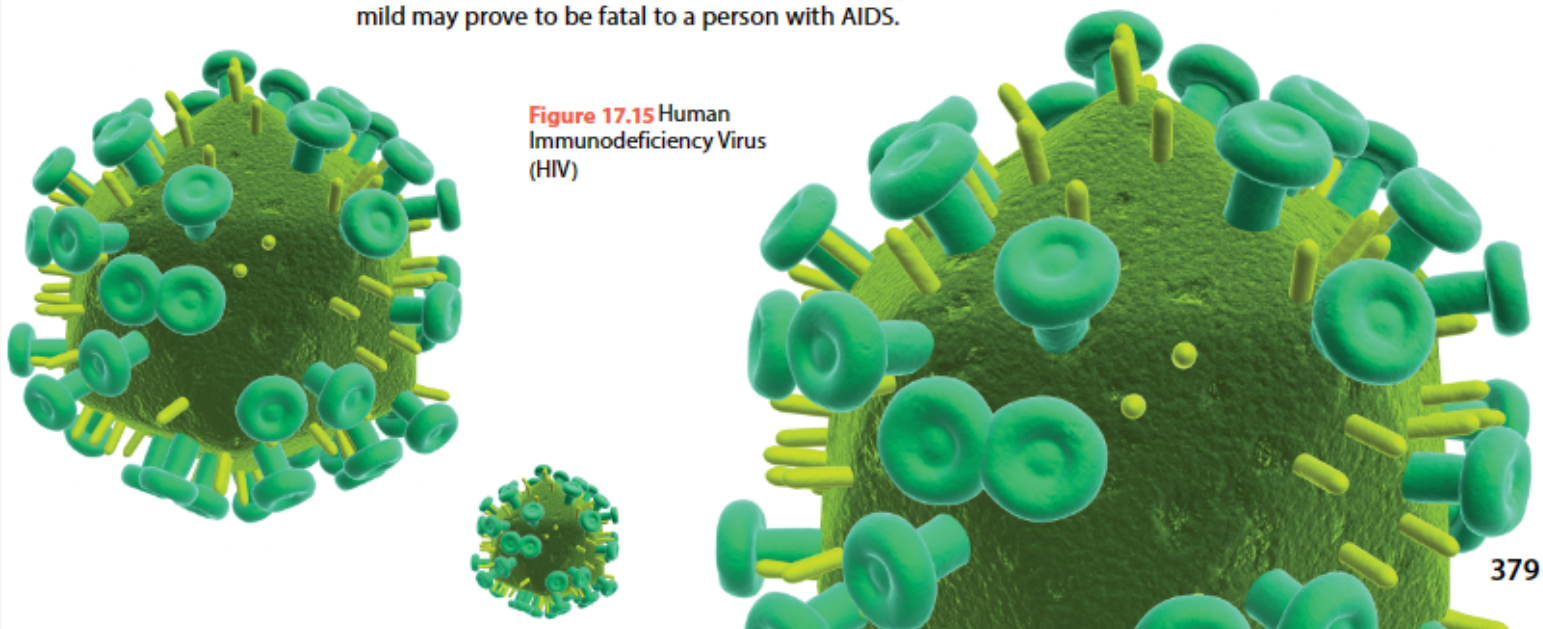
Normally, when foreign particles such as bacteria or viruses enter our bloodstream, our white blood cells (lymphocytes) are able to identify them. The white blood cells are then stimulated to produce antibodies to destroy the bacteria and viruses. In this way, our immune system protects our bodies against many diseases. HIV destroys a person's immune system by destroying the white blood cells. The body is unable to produce sufficient antibodies to protect the person against many other diseases. Therefore, infections which are normally mild may prove to be fatal to a person with AIDS.



Link

How do lymphocytes protect the body from bacteria and viruses? Recall what you have learnt about white blood cells in Chapter 6.

Figure 17.15 Human Immunodeficiency Virus (HIV)



What Are the Signs and Symptoms of AIDS?

It may take months to years before HIV infection develops into AIDS. Figure 17.16 shows some signs and symptoms of AIDS.

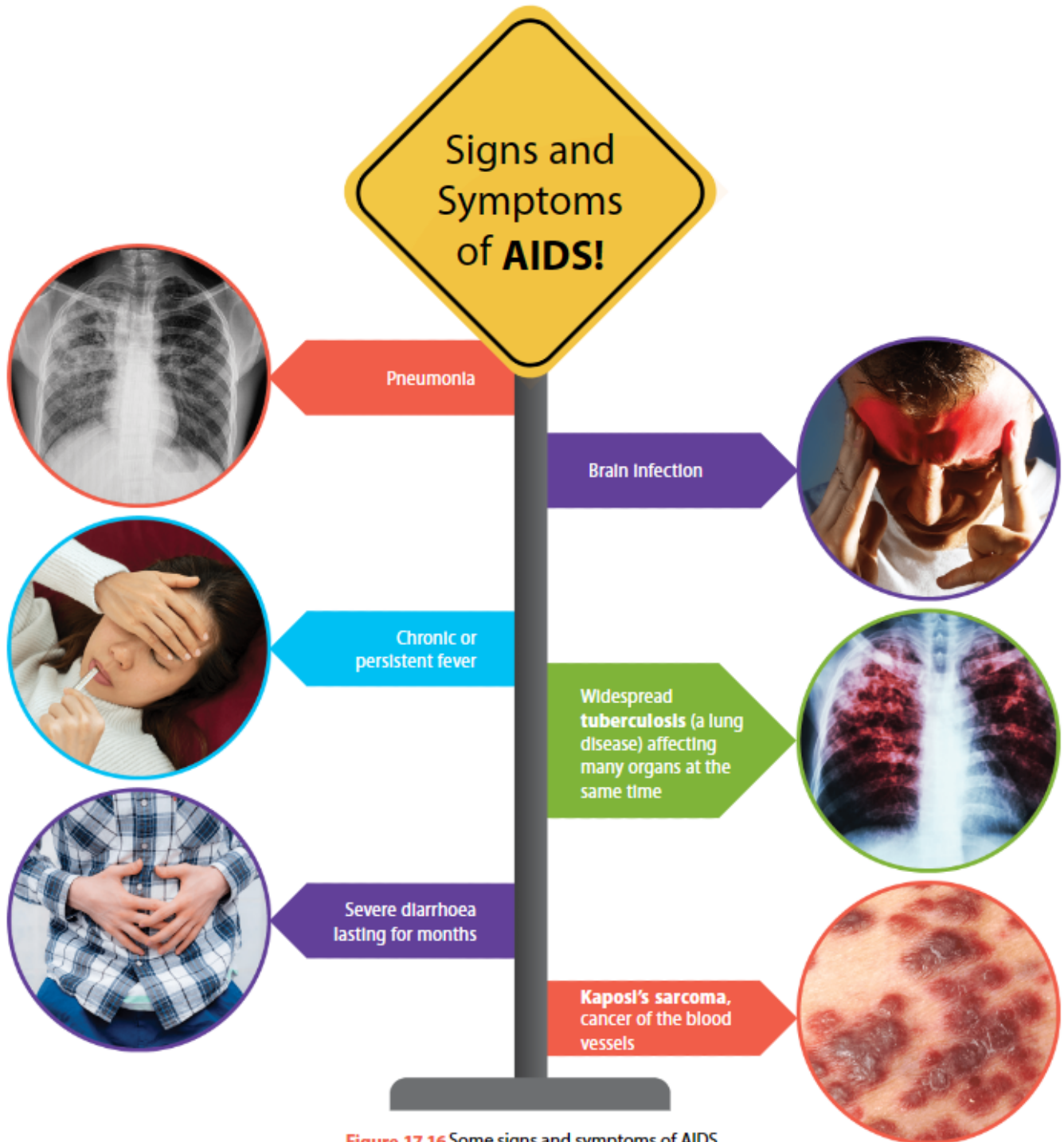


Figure 17.16 Some signs and symptoms of AIDS

AIDS is called a 'syndrome' because it is a disease with many signs or symptoms occurring at the same time. So far, no cure has been found.

How Is HIV Transmitted?

HIV is usually transmitted via the following modes:

- through sexual intercourse with an infected person
- through sharing hypodermic needles with an infected person
 - This can happen, for example, when drug addicts share their needles.
 - Needles used for tattooing, acupuncture or ear-piercing may also transmit the disease if they are not sterilised properly.
- through blood transfusion with blood from an infected person
 - The World Health Organisation (WHO) recommends that all blood donations be screened for evidence of infection before use. In Singapore, this is usually not a problem because all donated blood is carefully screened before use.
- through pregnancy
 - The virus may pass from the infected mother to the fetus.

HIV is not spread through toilet seats, doorknobs, coughing, swimming pools or mosquitoes.

How Can We Prevent and Control HIV Transmission?

These are some ways to reduce the risk of getting infected with HIV and to control its spread:

- Keep to one sexual partner or abstain from having sexual intercourse.
- Males should wear a condom if they are not sure whether their partner(s) or themselves are infected with AIDS. This reduces the risk of infection.
- Do not share instruments that are likely to break the skin and be contaminated with blood, for example, razors and toothbrushes.
- Go to reliable operators if you require acupuncture treatment, ear-piercing or tattooing. Make sure that the needles used are **sterilised** or insist on using disposable instruments. Sterilisation removes living microorganisms such as bacteria and viruses from the instruments.



Figure 17.17 Do not share personal care items with others to reduce the risk of HIV infection.



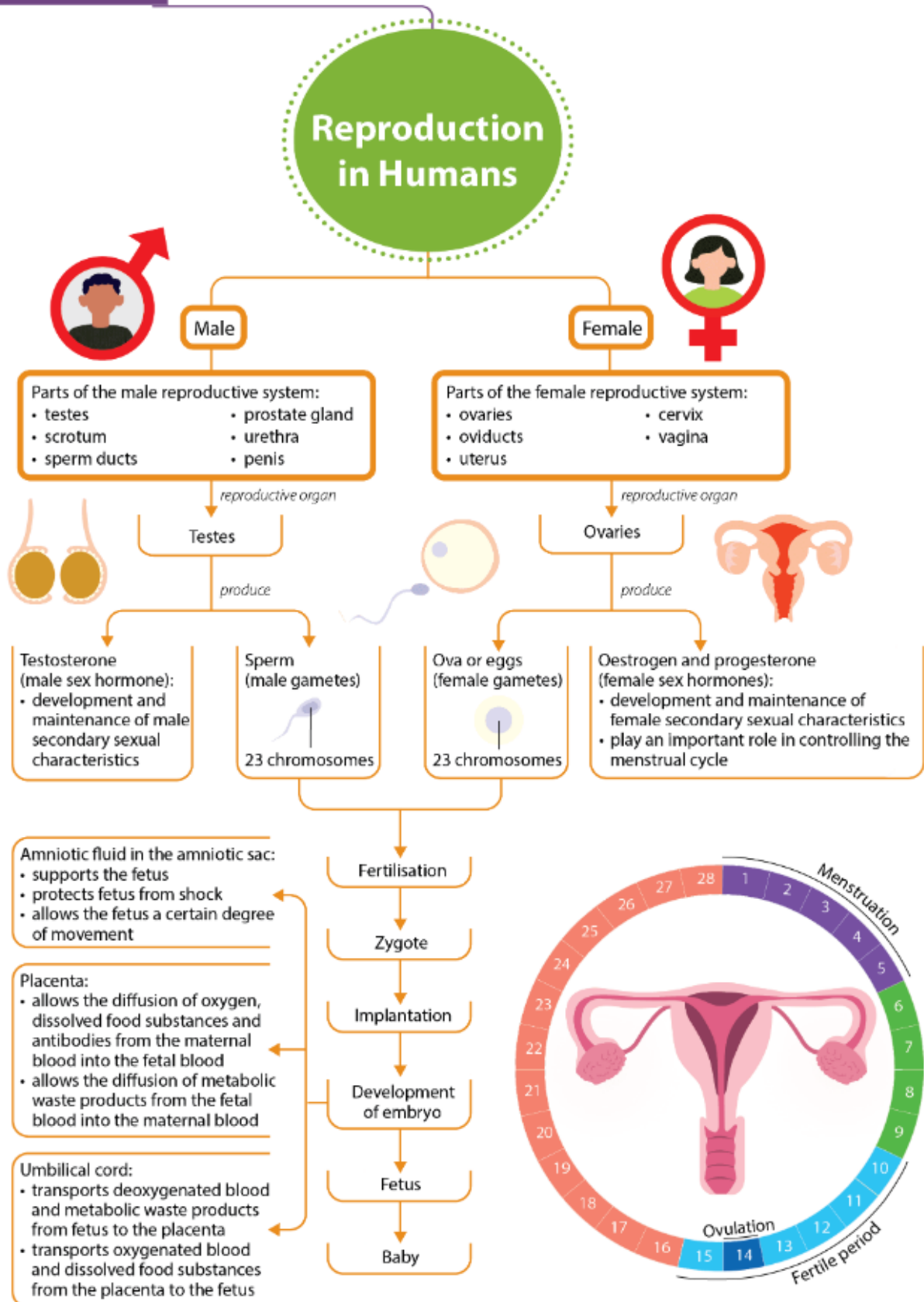
Link

Theory Workbook
Worksheet 17D
Let's Assess
Let's Reflect

Let's Practise 17.4

- 1 Name the pathogen that causes AIDS.
- 2 State **two** ways by which HIV can be transmitted.

Let's Map It



Let's Review

Section A: Multiple-choice Questions

- 1 Figure 17.18 shows the male reproductive system.

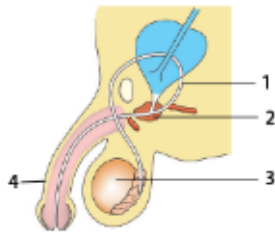


Figure 17.18

Which structure produces the fluid part of the semen and where are sperm stored when they are still in their inactive form?

	Structure Involved in the Production of the Fluid Part of Semen	Structure That Stores Sperm When They Are Still in Their Inactive Form
A	1	2
B	1	3
C	2	3
D	3	4

- 2 Figure 17.19 shows some structures in the abdomen of a female. What are the structures X, Y and Z?

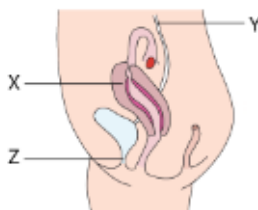


Figure 17.19

	Uterus	Urethra	Ureter
A	X	Y	Z
B	Y	X	Z
C	X	Z	Y
D	Y	Z	X

- 3 Which of the following substances is/are usually prevented from crossing the placenta and entering fetal bloodstream?

- ☐ A antibodies
☐ B carbon dioxide
☐ C haemoglobin
☐ D urea

- 4 Which blood vessel carries highly oxygenated blood away from the gaseous exchange surface and towards the human fetus?

- ☐ A aorta
☐ B pulmonary artery
☐ C pulmonary vein
☐ D umbilical vein

- 5 When is ovulation most likely to occur?

- ☐ A about halfway between the start of menstruation and the next cycle
☐ B at the beginning of menstruation
☐ C 1-6 days before the start of menstruation
☐ D 6-10 days after the start of menstruation

Section B: Structured Questions

- 1 Figure 17.20 shows a side view of a male reproductive system.

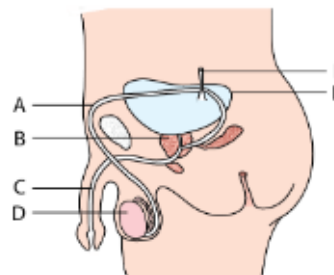


Figure 17.20

- (a) Name the parts labelled A to F.
 (b) Using the letters A to F, state the part:
 (i) that both urine and sperm pass through;
 (ii) that only sperm pass through;
 (iii) where male sex hormones are produced.
 (c) State the route of a sperm from the testis to the outside of the body.

- 2 Figure 17.21 shows the relative thickness of the lining of the uterus in a woman during her menstrual cycle.

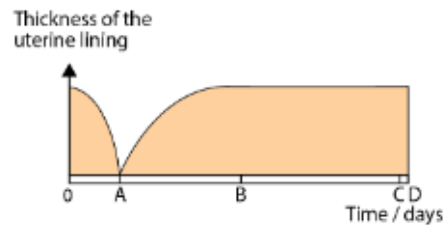


Figure 17.21

- What happens between day 0 and day A?
 - What is the average length of time between day 0 and day A?
 - What happens to the uterine lining during the time between day A and day B?
 - What happens to the uterine lining in the time between day B and day C?
 - Place the letter X on the diagram at the point when fertilisation is likely to take place if sexual intercourse occurs.
- 3 Figure 17.22 shows a fetus just before birth.

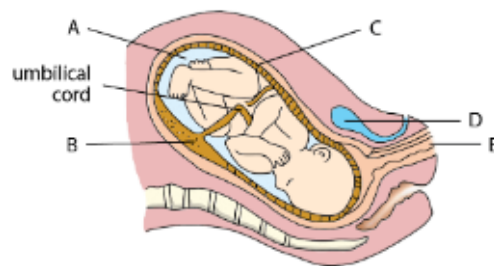


Figure 17.22

- Name the structures labelled A to E.
- State **one** function each of A and B.

- (c) Figure 17.23 shows a transverse section through the umbilical cord.

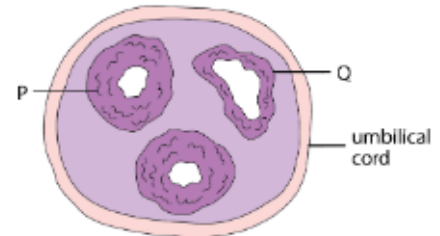


Figure 17.23

- Name the structures labelled P and Q, and give a reason for your answer.
- State the functions of P and Q.

Section C: Free-response Questions

- Describe the main stages in the menstrual cycle. Explain how the hormones oestrogen and progesterone help in controlling the cycle.
- What are sexually transmitted infections?
 - Explain how the spread of AIDS can be prevented and controlled.

CHAPTER

18 Inheritance



What You Will Learn



- What is the mechanism of inheritance?
- What is some basic knowledge needed for studying inheritance?
- How are ABO blood groups inherited?
- How is sex determined?
- What is variation?
- What is natural selection?

Look at these kittens. They all belong to the same set of parents, yet they look different from one another. Why do you think this is so?

18.1 What Is the Mechanism of Inheritance?

Learning Outcomes

- Understand monohybrid inheritance, including terms such as F_1 generation and F_2 generation.
- Explain the terms *dominant* and *recessive*.
- Explain why observed ratios often differ from expected ratios, especially when there are small numbers of progeny.



Word Alert

Inherited: passed on

'You have your father's nose!' or 'You have your mother's eyes!' — such remarks are quite commonly heard. Parents bear children that resemble them, but not exactly — more like a mix of features from each parent. How does this come about?

Why Do We Look Like Our Parents?

Your height, eye colour and skin colour are some traits or characteristics that are passed on to you from your parents. These are referred to as hereditary traits (Figure 18.1) because they can be **inherited** from one generation to another.

► **Inheritance** refers to the transmission of traits from one generation to another.

For many centuries, it was observed that traits could be inherited. However, scientists were unable to explain how such traits were inherited until the middle of the 19th century!



Figure 18.1 Some human traits that can be inherited



Figure 18.2
Gregor Mendel

What Is Monohybrid Inheritance?

In the 19th century, Gregor Mendel (Figure 18.2) first explained how heredity might work. Mendel carried out breeding experiments on garden pea plants (*Pisum sativum*). First, he experimented with plants with one pair of contrasting traits, such as:

- tallness and shortness of the plant
- plants that had either red or white flowers
- plants which produced seeds that were either yellow or green, or round or wrinkled

Mendel also used pure-bred **varieties** of pea plants. Pure-bred plants are plants which, when *self-fertilised* (*self-pollinated*), produce offspring (**progeny**) that resemble their parent. For example, when pure-bred tall plants self-fertilise, they produce only tall offspring.

Mendel's Monohybrid Experiments

Figure 18.3 shows how Mendel conducted his monohybrid experiment using pea plants.

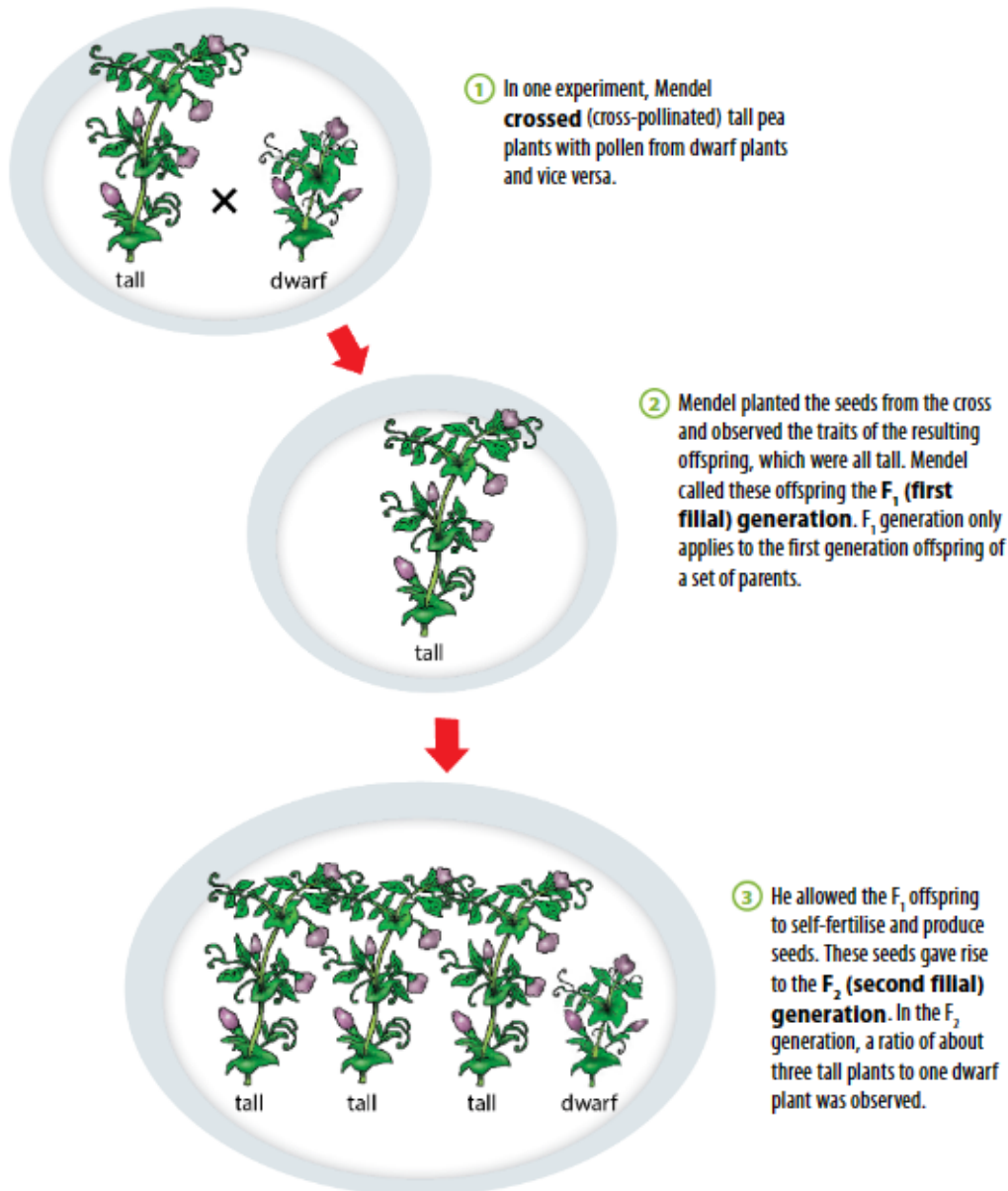


Figure 18.3 One of Mendel's experiments involving monohybrid inheritance

In all his experiments, Mendel observed that one trait always appeared in the F₁ offspring (long stems). Mendel called this trait **dominant**. The other trait (short stems) seemed to disappear or 'recede'. Mendel called this trait **recessive**. The recessive trait reappeared in about one-quarter of the total number of F₂ offspring.



Word Alert

Varieties: different types or kinds



Link

In order for fertilisation to take place, some plants need to undergo pollination. Recall what you have learnt in Chapter 16.



Helpful Note

An organism possessing a dominant trait is not healthier or stronger than an organism with the recessive trait and vice versa. Certain fatal diseases in humans, for example, retinoblastoma, which causes tumours in the eyes, are due to dominant traits. Similarly, there are also fatal diseases caused by recessive traits, for example, sickle cell anaemia, a disorder of the blood.

Mendel also made crosses using six other pairs of contrasting traits in pea plants. The results of these crosses are shown in Table 18.1.

Table 18.1 Mendel's monohybrid experiments

Traits in Parent Plants	Traits in F ₁ Generation (All Are Dominant)	Traits in F ₂ Generation	Ratio of Dominant Traits to Recessive Traits in F ₂ Generation
 ×  Round seed Wrinkled seed	All round	5474 round 1850 wrinkled	2.96 : 1
 ×  Yellow seed Green seed	All yellow	6022 yellow 2001 green	3.01 : 1
 ×  Purple flower White flower	All purple	705 purple 224 white	3.15 : 1
 ×  Inflated pod Constricted pod	All inflated	882 inflated 299 constricted	2.95 : 1
 ×  Green pod Yellow pod	All green	428 green 152 yellow	2.82 : 1
 ×  Axial flower Terminal flower	All axial	651 axial 207 terminal	3.14 : 1
 ×  Long stem Short stem	All long	787 long 277 short	2.84 : 1

Why Does the Observed Ratio Often Differ from the Expected Ratio?

You may have noticed from Table 18.1 that the ratio in the F₂ generation becomes closer to the expected ratio of 3:1 when a larger number of plants are used in the experiment. If a smaller number of plants are used, the observed ratios for the F₂ generation are not accurate. Statistically, ratios are often inaccurate when the sample numbers are small.

The observed ratio is also based on chance and probabilities due to the random nature of fertilisation. Hence, the actual number of offspring would be unlikely to match the expected ratio precisely.

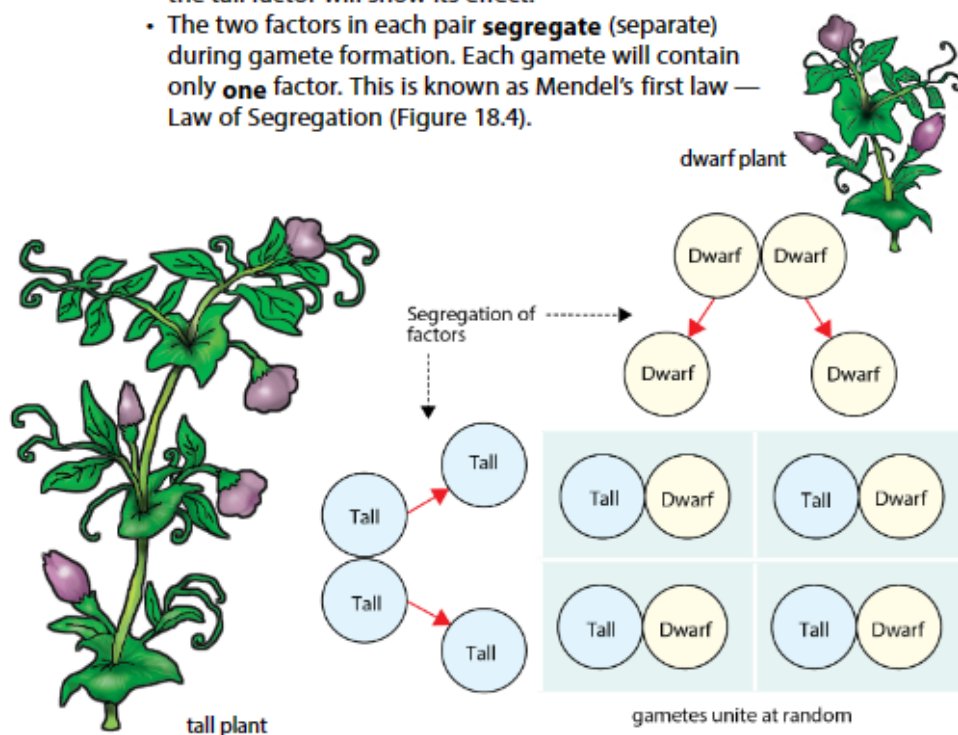
Mendel's Model of Heredity

Like all good scientists, Mendel was interested in explaining, not just in describing, the observations he had made about his pea plants. He suggested the following model to explain the inheritance of the characteristics he had studied.

- Hereditary factors are responsible for the transmission of characteristics. These hereditary factors are now known as **genes**.

▶ A **gene** is a sequence of DNA nucleotides that controls the formation of a single polypeptide. It is also a unit of inheritance.

- Each characteristic is controlled by a pair of factors in the cells of an organism. For example, the height of a pea plant is controlled by a pair of factors. *If the two factors differ, only the dominant one will show its effect.* So if a pea plant contains one factor for tallness and one for dwarfness, only the tall factor will show its effect.
- The two factors in each pair **segregate** (separate) during gamete formation. Each gamete will contain only **one** factor. This is known as Mendel's first law — Law of Segregation (Figure 18.4).



- The fusion of gametes at fertilisation restores the diploid condition in the zygote, that is, the zygote contains two factors (one factor from each parent) for a particular characteristic.
- Gametes unite at random so that the ratio of characteristics among the offspring can be predicted.

Let's Practise 18.1

- A student carried out a monohybrid experiment on 50 pea plants to study the inheritance of height in these plants. He did not obtain the expected 3:1 ratio in the F₂ generation predicted by Mendel's theory. Assuming there is no experimental error, why is the experimental result different?



Link

Recall what you have learnt about genes in Chapter 14.



Disciplinary Idea

Heredity

The chromosomal basis of inheritance (Mendel's laws of segregation) sheds light on the passing down of genetic information from parent to offspring.

Figure 18.4
Mendel's Law of Segregation

18.2 What Is Some Basic Knowledge Needed for Studying Inheritance?

Learning Outcomes

- Distinguish between the terms *gene* and *allele*.
- Explain the terms *codominant*, *homozygous*, *heterozygous*, *phenotype* and *genotype*.
- Predict the results of simple crosses with expected ratios of 3:1 and 1:1, using the terms *homozygous*, *heterozygous*, *F₁ generation* and *F₂ generation*.
- Use genetic diagrams to solve problems involving monohybrid inheritance.



Word Alert

Heredity: another word for *inheritance*



Link

Recall what you have learnt about the definition of a gene in Chapter 14.

Recall what you have learnt about the definition of a homologous chromosome in Chapter 15.

Mendel's model of inheritance forms the basis of modern genetics. Scientists now know much more about what is involved in **heredity** and have developed new scientific terms to explain what is happening.

What Are Alleles?

Our normal body cell has two haploid sets of chromosomes, having inherited one set from each parent. Hence, each chromosome is represented as a pair in each cell. You have learnt that genes are the heredity factors found in the chromosomes. They are responsible for the passing down of traits. Each gene may exist in two or more different (or alternative) forms.

The different forms of the same gene are called **alleles**. Alleles occupy the same relative position on a pair of homologous chromosomes.

For example, the eyelid gene has two different alleles. One allele gives you double eyelids and the other gives you single eyelids (Figure 18.5). If you have inherited two different alleles from your parents, you will have double eyelids. How could this be? When a person has two different alleles, one allele will express itself, while the other will not. In this case, the double-eyelid allele expresses itself, while the single-eyelid allele is not expressed. Why is this so?

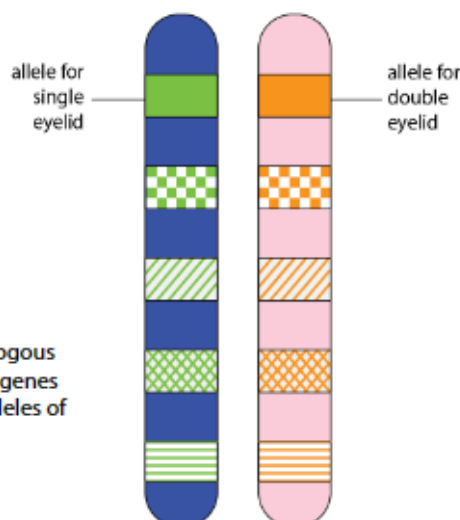


Figure 18.5 A pair of homologous chromosomes, showing five genes in each chromosome. Two alleles of the eyelid gene are shown.

If a person has two different alleles, the allele that expresses itself is called the **dominant allele**, while the other is called the **recessive allele**. The double-eyelid allele is dominant.



Can a Recessive Allele Express Itself?

A recessive allele can express itself in a person when the person has both recessive alleles in the gene. Thus, a person with two alleles for single eyelid will have single eyelids.



Single eyelid is expressed when both alleles are recessive.



Double eyelid is expressed when one or both alleles are dominant.

Figure 18.6 Single eyelid and double eyelid gene expressions

Let us use symbols to represent the alleles.

Example: D = dominant allele d = recessive allele

- ▶ The combination of alleles for a particular gene is called **genotype**. The expressed trait or outward appearance is called **phenotype**.

Table 18.2 shows the different genotypes with their corresponding phenotypes.

Table 18.2 Eyelid genotypes and phenotypes

Genotype	Phenotype
DD	Double eyelids
Dd	Double eyelids
dd	Single eyelids

Homozygous and Heterozygous

The terms *homozygous* and *heterozygous* are used to describe the allele combination (genotype) of the organism.

- ▶ **Homozygous** refers to having two identical alleles of a particular gene (e.g. DD or dd).

An organism that is **homozygous dominant** for a certain trait or gene has two dominant alleles for the gene (e.g. DD).

An organism that is **homozygous recessive** for a certain trait or gene has two recessive alleles for the gene (e.g. dd).

- ▶ **Heterozygous** refers to having two different alleles of a particular gene (e.g. Dd).

Hence, a dominant allele expresses itself and gives the same phenotype in both the homozygous and heterozygous condition. A recessive allele is only expressed in the homozygous condition. An organism is pure-bred if it contains identical alleles (e.g. TT or tt). A pure-bred is a homozygous organism.



Helpful Note

A homozygous organism has two identical alleles for a particular gene and is also called a **homozygote**.

A heterozygous organism has two different alleles for a particular gene and is also called a **heterozygote**.

Genetic Diagrams

Geneticists use genetic diagrams to explain how alleles are passed on to an offspring and what traits will be expressed by the offspring (a genetic cross). The genetic diagram in Figure 18.7 explains Mendel's results. Since the F_1 offspring (heterozygous) were all tall, it means the dominant phenotype is tall.

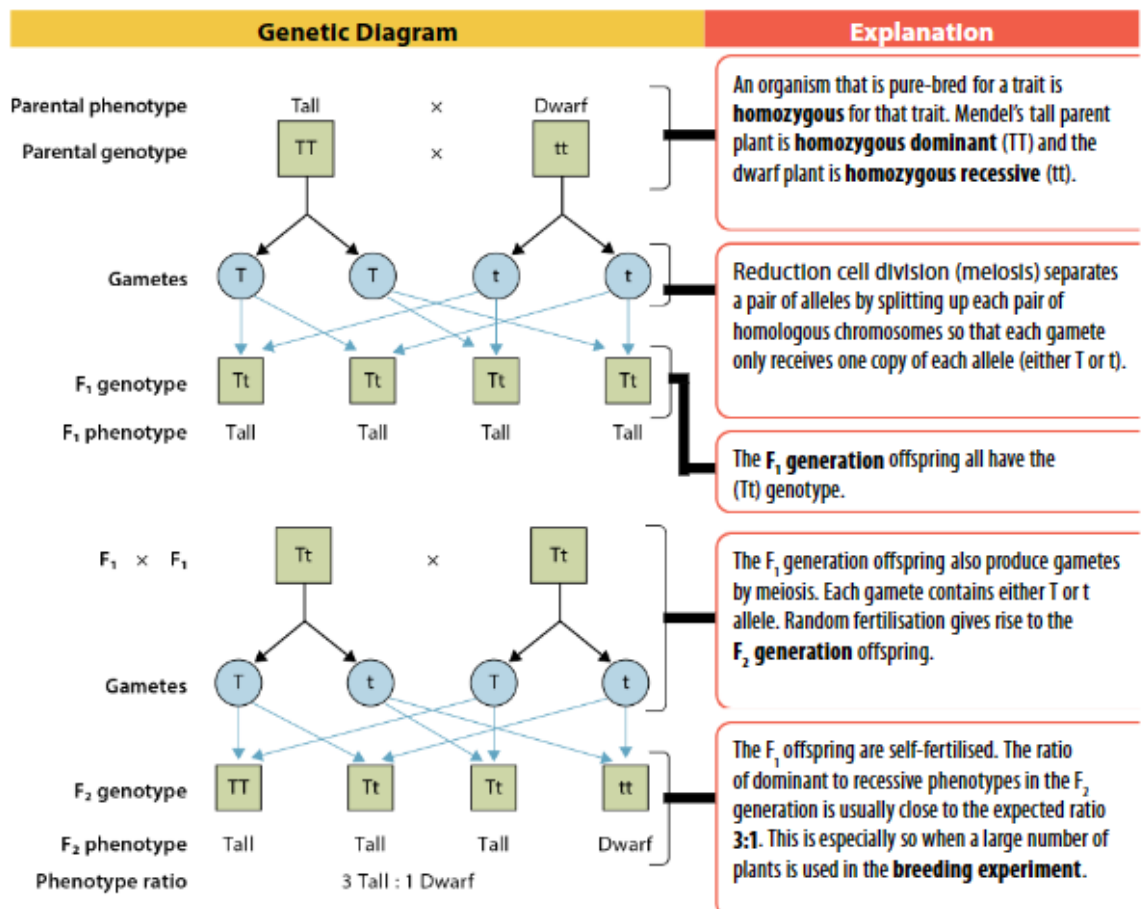
Let T be the dominant allele for tall plants.
Let t be the recessive allele for dwarf plants.

Figure 18.7 Genetic diagram showing inheritance of alleles for tallness and dwarfness in pea plants



Helpful Note

When you draw a genetic diagram, it is not compulsory to write the genotypes within boxes.



Another way of presenting the results is to use a **Punnett square** (Figure 18.8).

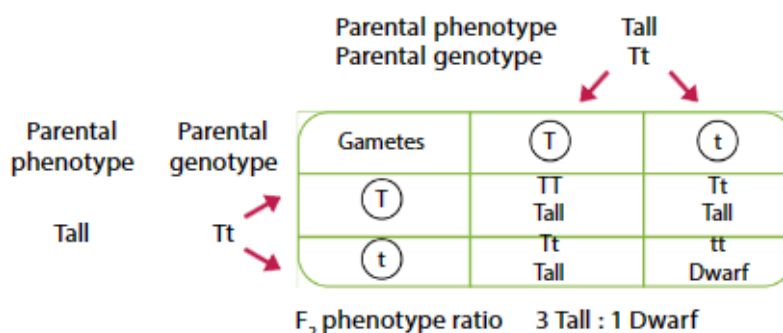


Figure 18.8 Punnett square



Test Cross

In pea plants, tall is a dominant phenotype. If you are given a tall pea plant, how can you find out whether it is homozygous dominant (TT) or heterozygous (Tt)?

To find out the genotype of an organism showing the dominant characteristic, we carry out a **test cross**. A test cross always uses a homozygous recessive organism.

If the plant is homozygous dominant, all the offspring will be tall (Figure 18.9(a)).

If the plant is heterozygous, the offspring will be in the ratio 1 tall : 1 dwarf, or dwarf offspring will appear (Figure 18.9 (b)).

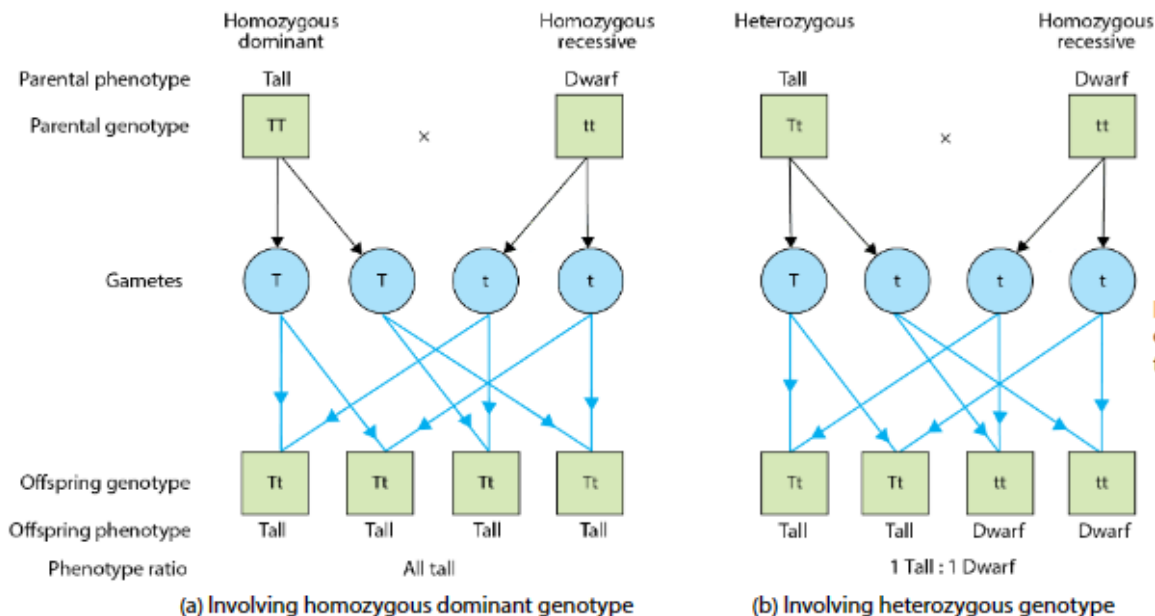


Figure 18.9 Genetic diagrams showing two test crosses

Worked Example 18A

Figure 18.10 shows the inheritance of hair colour in members of a family.

- Which is the dominant phenotype?
- What is the genotype of A, homozygous or heterozygous?
- What is the most likely genotype of F? Is he homozygous dominant or heterozygous?
- Can you confirm that F is homozygous dominant?

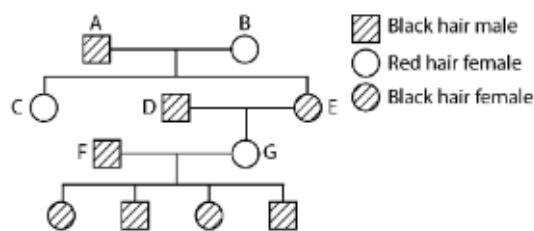


Figure 18.10

Solution

- Black hair. Child G has red hair. Both of her parents, D and E have black hair. This means that they are heterozygous. They have the red hair allele that is not expressed in them.
- Heterozygous
- He is most likely to be homozygous dominant.
- No. There are too few children to give any reliable deduction. Genetic ratio is unreliable in small numbers.



Helpful Note

A pedigree chart shows the inheritance of a trait within a family across generations. In a pedigree chart, males are represented by squares and females by circles. A horizontal line linking a male and female represents mating and have one or more offspring. A vertical line links the parents to their offspring.



Word Alert

Roan: an animal, especially a horse or cow, having a coat of a main colour mixed with hairs of another colour

Codominance

When a red-haired bull mates with a white-haired cow, their offspring has both red hairs and white hairs, called **roan**. This is an example of **codominance**.

In **codominance**, both alleles express themselves in the heterozygote, which has a phenotype intermediate between that of its pure-bred parents. The alleles are said to be **codominant**.

Worked Example 18B

A pure-bred red-haired bull mated with a pure-bred white-haired cow. All their offspring were roan. When their roan offspring interbred among themselves, they produced offspring in the ratio 1 red : 2 roan : 1 white.

Using suitable symbols, explain the above crosses.

Solution

Since the offspring were roan, it means that the allele for red hair and the allele for white hair both expressed themselves in the heterozygote.

Let R be the allele for red hair and W be the allele for white hair, where R and W are codominant. From Figure 18.11, we can see how the ratio 1 red : 2 roan : 1 white is obtained.

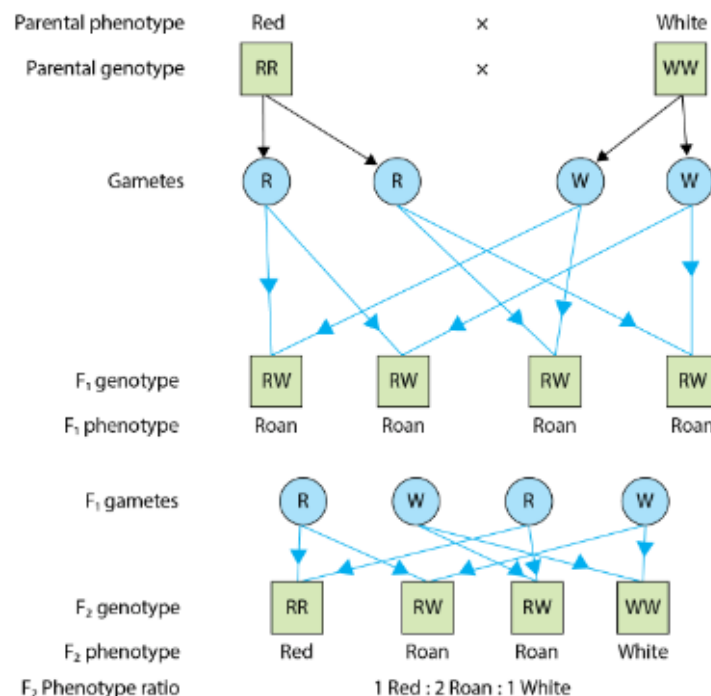


Figure 18.11 Genetic diagrams showing the cross between the parental gametes and the cross between the F₁ gametes.

You have learnt how alleles express themselves. Comment on the opinions of the two people in Figure 18.12. Explain why they are correct or incorrect.



Figure 18.12 Two people are comparing dominant and recessive alleles. Comment on their opinions.

Let's Practise 18.2

- 1 In a breeding experiment, a homozygous recessive brown horse was crossed with a heterozygous black horse. What is the probability of the offspring being heterozygous?



Link

Theory Workbook
Worksheet 18A–18B

18.3 How Are ABO Blood Groups Inherited?

Learning Outcome

- Explain codominance and multiple alleles with reference to the inheritance of the ABO blood group phenotypes (A, B, AB, O) and the gene alleles (I^A , I^B and I^O).

You have learnt that genes can exist in two or more different forms called alleles. In many of the traits you have encountered, each involves two different alleles of a gene. However, when genes have more than two different forms, they are said to have *multiple alleles*.

- ▶ A gene that exists in more than two different forms is said to have **multiple alleles**.



Link

Blood type has no bearing on the functions of blood. What are the functions of blood?

Look back to Chapter 6 on Transport in Humans.

An individual can only have two alleles, one allele from each parent. With multiple alleles, there can be different combinations of the two alleles. This makes it possible to have more than two phenotypes expressed based on the dominant or recessive alleles available in the trait.

The gene for human blood group is an example of a gene with multiple alleles. There are four blood groups in human populations, namely A, B, AB and O. The alleles for blood groups A, B and O are designated I^A , I^B and I^O respectively. I^A and I^B are dominant over I^O , but I^A and I^B exhibit codominance. Therefore, individuals with alleles I^A and I^B will have the blood group AB. The blood groups and their respective genotypes are shown in Table 18.3.

Table 18.3 Human blood groups and their corresponding genotypes

Blood Group	Genotype
A	$I^A I^A$ or $I^A I^O$
B	$I^B I^B$ or $I^B I^O$
AB	$I^A I^B$
O	$I^O I^O$

Worked Example 18C

A man of blood group A is married to a woman of blood group B. They have a child whose blood group is O.

- Explain, by means of a genetic diagram, how it is possible for the couple to have a child with blood group O.
- What is the probability that their next child will have blood group O?

Solution

Let I^A , I^B and I^O be the alleles for blood group A, B and O respectively. I^A and I^B are dominant to I^O . I^A and I^B are codominant, and together will give AB blood group.

- For a child to have blood group O, he must have the genotype $I^O I^O$. This means both his parents must have an I^O allele. His father's genotype must be $I^A I^O$ and his mother's genotype $I^B I^O$ (Figure 18.13).

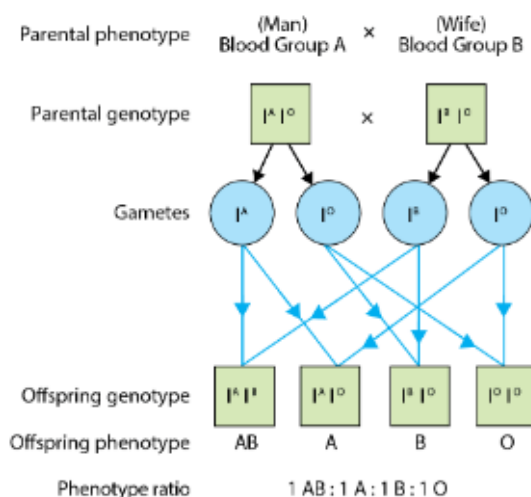


Figure 18.13

- The probability that the next child will have blood group O is $\frac{1}{4}$ or 25%.



Link

Theory Workbook
Worksheet 18C

Let's Practise 18.3

- A man has blood group A. His wife has group O. Explain with a genetic diagram how they are able to have a child with blood group O.

18.4 How Is Sex Determined?

Learning Outcome

- Describe the determination of sex in humans — XX and XY chromosomes.

When a child is conceived, we do not know yet the sex of the baby until a certain time. As early as 14 weeks into the pregnancy, ultrasound may reveal the sex of the baby inside the womb. People in olden times used to rely on things such as the shape of the mother's belly or simply waited till childbirth to find out the sex of the baby. What determines whether the baby is a boy or a girl?

In a human body cell, there is one pair of **sex chromosomes** and 22 pairs of non-sex chromosomes called **autosomes**. This means that each human body cell has one pair of each type of chromosome. Hence, human body cells are diploid with 23 pairs of chromosomes. In males, the pair of sex chromosomes consists of one X chromosome and one shorter Y chromosome (Figure 18.14). Females have a pair of X chromosomes in each normal body cell (Figure 18.15).

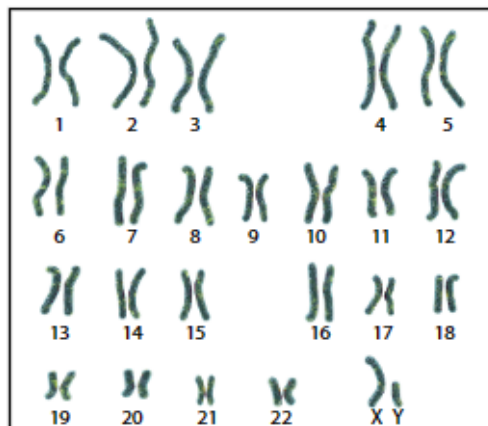


Figure 18.14 Chromosomes of a male

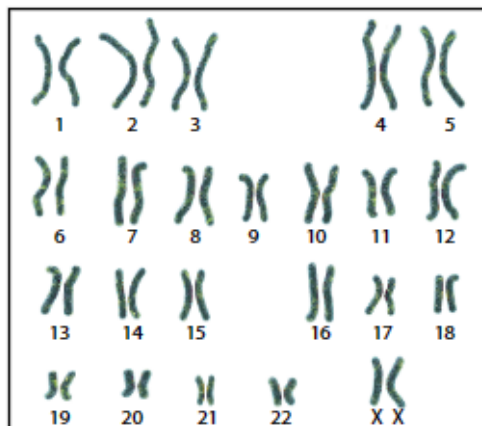


Figure 18.15 Chromosomes of a female

During gamete formation, each gamete produced can only have one chromosome from each pair of chromosomes. In the male, the sperm produced contains either a Y or an X chromosome. In the female, each egg will contain one X chromosome (Table 18.4). The Y chromosome is shorter than the X chromosome.

Table 18.4 Sex chromosomes in humans

Individual's Sex	Human Sex Chromosomes
Male	X Y
Female	X X

Random fertilisation will enable a couple to have equal chances of producing a boy or a girl (Figure 18.16).

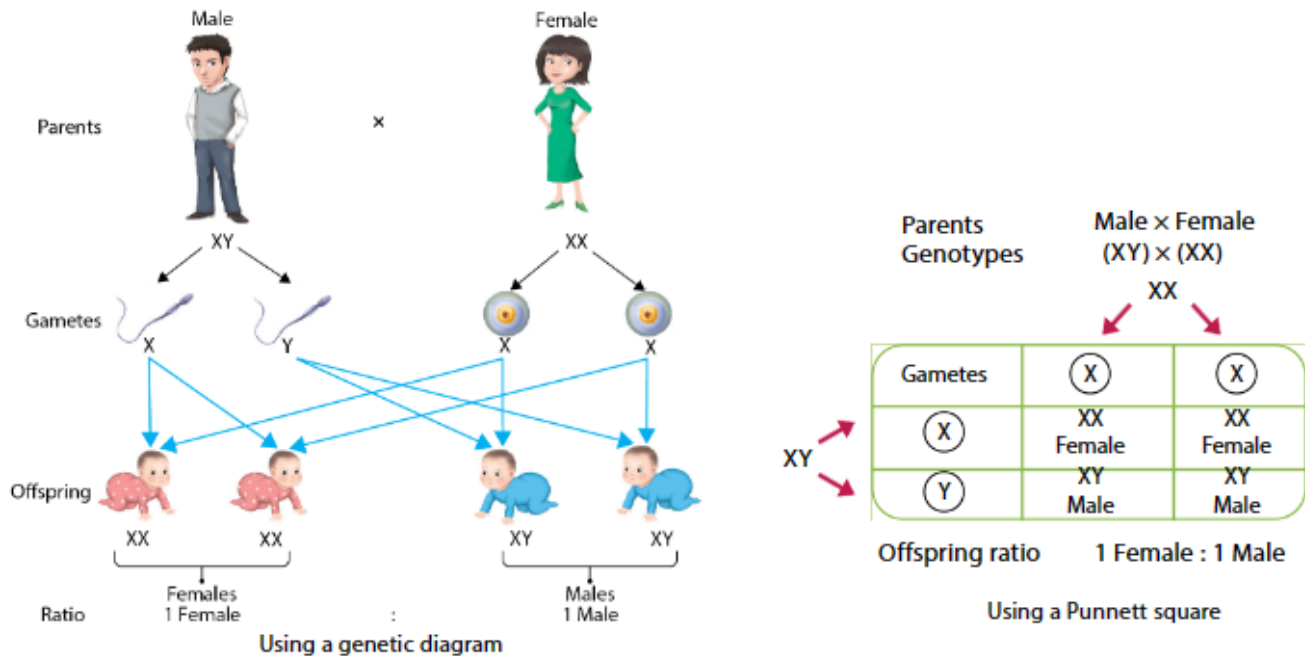


Figure 18.16 Sex determination in humans

The offspring will have an equal chance of being male or female.

Table 18.5 shows the difference in the chromosomes found in the male and female.

Table 18.5 Number of chromosomes in body cells and in gametes

	Number of Chromosomes in Body Cells	Number of Chromosomes in Gametes
Male	44 non-sex chromosomes + X + Y	22 non-sex chromosomes + X or 22 non-sex chromosomes + Y
Female	44 non-sex chromosomes + X + X	22 non-sex chromosomes + X

Let's Investigate 18.1

Two students carried out an experiment on inheritance. Each student is provided with a spinner with the letters T and t as shown in Figure 18.17. Since fertilisation is random, a spinner is used to represent this random probability.

Both students will spin the discs at the same time. When the disc stops with one side nearest the surface of the table, the letters are recorded. They will repeat the procedure on 80 separate occasions.

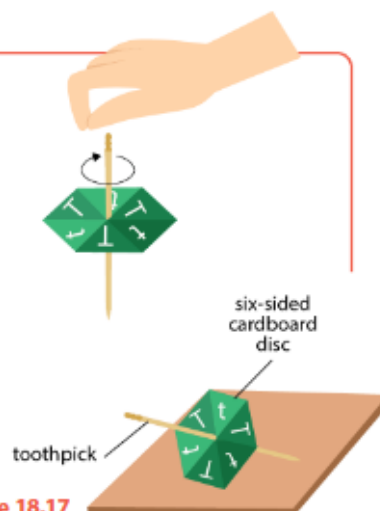


Figure 18.17

- (a) Complete Table 18.6 to show the expected results obtained.

Table 18.6

Combination of Letters on Each Occasion	Number of Times Each Combination of Letters Is Recorded
T and T	20
T and t	
t and t	

- (b) Suggest two reasons why the results may be different from the expected results.
 (c) What does the spinning of the discs represent?
 (d) What do the letters represent?

Let's Practise 18.4

- The sex of the human baby is determined by the male gamete. True or false?
- Figure 18.18 shows the chromosomes of a human.
 - Identify chromosomes A and B.
 - Is this person male or female?
- The normal human body cell contains 46 chromosomes. How many non-sex chromosomes are present in the sperm cell?

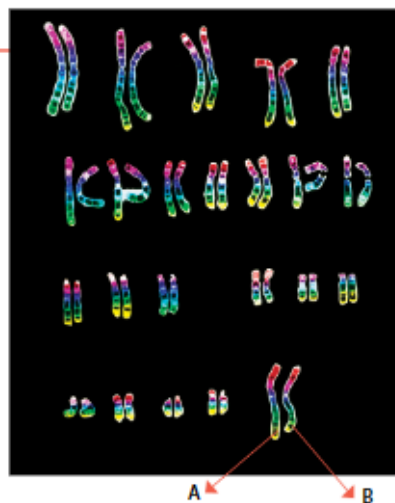


Figure 18.18



Link

Theory Workbook
Worksheet 18D

18.5 What Is Variation?

Learning Outcomes

- Distinguish between *continuous* and *discontinuous* variation and give examples of each.
- Describe *mutation* as a change in the sequence of a gene such as in sickle cell anaemia, or in the chromosome number, such as the 47 chromosomes in the condition known as Down syndrome.
- Name ionising radiation (e.g. X-ray) and chemical mutagens as factors which may increase the rate of mutation.

Have you noticed that some people have single eyelids while others have double eyelids? You may have also noticed that some people can roll their tongues while others cannot. These are some examples of variations in traits found in humans.



► **Variation** refers to the differences in traits between individuals of the same species.

There are traits that show **discontinuous variation** (Figure 18.19), which is controlled by one or a few genes. In discontinuous variation, there are clearly defined differences with few or no intermediate forms.

Here are examples of traits showing discontinuous variation:

- 1 The traits show clear-cut phenotypes with no intermediate forms between the traits. For example, in Mendel's experiment, the seeds of pea plants were either green or yellow and either smooth or wrinkled.
- 2 The traits are easily distinguishable and are not affected by environmental conditions. Examples of such traits in humans are the ABO blood groups, double or single eyelids and the ability to roll the tongue.

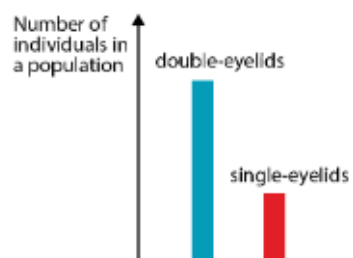


Figure 18.19 Graph showing discontinuous variation

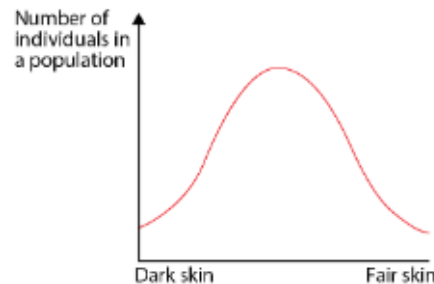


Figure 18.20 Graph showing continuous variation

However, not all traits show discontinuous variation. Humans are not just dark or fair, tall or short.

There are many intermediate skin colours and heights. Such range of traits show a **continuous variation** (Figure 18.20). Continuous variation is brought about by the combined or **additive** effect of many genes.

There are genes for dark skin and genes for fair skin. Continuous variation is also affected by environmental conditions. For example, greater exposure to sunlight may cause a person to have darker skin. Other examples of traits that show continuous variation include height, shoe size and body type.

Table 18.7 shows some differences between discontinuous variation and continuous variation.

Table 18.7 Distinguishing discontinuous variation from continuous variation

Discontinuous Variation	Continuous Variation
Involves a few clear-cut phenotypes (e.g. green or yellow seeds in pea plants)	Involves a range of phenotypes (e.g. human skin colour)
Controlled by one or a few genes	Controlled by many genes
Genes do not show additive effect	Genes show additive effect
Relatively unaffected by environmental conditions	Greatly affected by environmental conditions

Let's Investigate 18.2**Objective**

To compare traits that show continuous variation and discontinuous variation

Procedure

- 1 In groups of five or six, investigate two traits: height and types of eyelids.
- 2 For each student, record the height and presence of single or double eyelids.
- 3 Draw a graph to represent the range of heights in the group.
Use an appropriate type of graph to present your data.
- 4 Draw a graph to compare the number of students who have single eyelids and those who have double eyelids. Use an appropriate type of graph to present your data.

Questions

- 1 Which trait shows continuous variation? Why?
- 2 Which trait shows discontinuous variation? Why?

**Link**

Practical Workbook
Experiments 18A–18C

What Are Some Sources of Genetic Variation?**Meiosis**

Recall what you have studied in meiosis. Meiosis produces genetically dissimilar gametes with different combinations of the parental chromosomes. This results in offspring produced that are genetically different.

**Link**

What is meiosis?
Recall what you have learnt in Chapter 15.

Random Fertilisation

Random fertilisation also contributes to variation among the offspring. During fertilisation, any one of the millions of sperms released can randomly fuse with an egg to form a unique zygote. As each gamete is unique, the offspring produced from the fusion of gametes during fertilisation will also be genetically different.

Mutation

Genes are usually passed on from one generation to another unchanged. Before a cell divides, chromosomes replicate or divide and the genes they carry are copied exactly. Heredity depends on this accurate gene copying or replication. Occasionally, an error may occur and the gene may be modified or the chromosome may be altered. This is called *mutation*.

- **Mutation** is a change in the sequence of a gene or in the chromosome number.

Diversity within a species is the outcome of mutations. **Gene mutation** produces variation between individuals as it results in new alleles of genes. If a mutation occurs during gamete production, the resulting genetic change can be inherited by the offspring.

Mutation may also result in a change in the number of chromosomes in an organism. This is called **chromosome mutation**.

Mutations can be inherited, i.e. they can be passed down through the gametes from parents to their offspring.

**Disciplinary Idea****Evolution**

Mutation gives rise to genetic variation within a population.



Figure 18.21 An albino girl appears very white due to the absence of pigments in the skin, hair and eyes.

Examples of conditions that result from gene mutation are albinism and sickle cell anaemia.

Albinism

Albinism is an example of recessive gene mutation. Individuals who are homozygous for the albinism allele are albinos. Albinism is characterised by the absence of pigments in the skin, hair and eyes (Figure 18.21). An albino individual has a reddish-white skin and white hair. Since the iris does not contain any pigment, it will appear red because of the colour of the blood vessels in it. Albinos are very sensitive to sunlight and their skin can get sunburnt easily.

Sickle Cell Anaemia

Sickle cell anaemia is an example of a gene mutation. The mutation results in a change in the structure of the gene. It involves a change in the sequence of bases or nucleotides in the DNA (Figure 18.22).

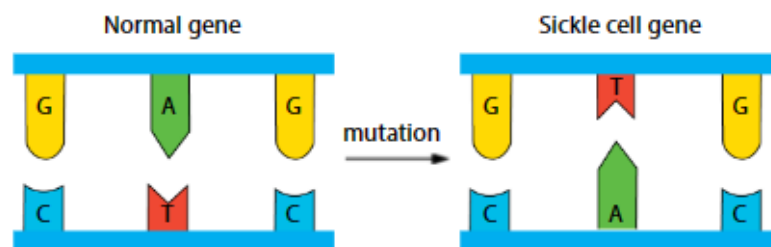


Figure 18.22 The sickle cell gene is a result of gene mutation.

The gene controlling haemoglobin production is involved in sickle cell anaemia (Figure 18.23).

Characteristics of Mutated Gene

- **Encodes haemoglobin S (HbS) protein in red blood cells**
HbS is almost the same as normal haemoglobin A (HbA) except in one amino acid. This causes a change in the 3-D shape of the haemoglobin molecule. HbS molecules clump together, making the cell sickle-shaped.



- ☐ **Dominant** ☒ **Recessive**

- **What this means:**
It is expressed only in the homozygous recessive condition.

People who are homozygous recessive have abnormal haemoglobin in their red blood cells. When oxygen concentration in their blood decreases, the red blood cells become sickle-shaped.

Figure 18.23 Sickle-shaped red blood cells are caused by gene mutation.

Sickle-shaped cells lose their ability to transport oxygen. They are fragile and sticky and can get stuck in narrow blood vessels. This slows or blocks the flow of oxygen to parts of the body. Sickle cell anaemia can be fatal.



Link

Sickle-shaped red blood cells do not have the special adaptations like normal red blood cells to help them transport oxygen efficiently. What are these adaptations? Recall what you have learnt in Chapter 6.

An example of a condition that result from a chromosome mutation is Down syndrome.

Down Syndrome

Sometimes, mutations may cause a change in the chromosome number. Humans normally have 46 chromosomes. However, some people have one extra chromosome — they have 47 chromosomes in their body cells. Normally, zygotes with extra chromosomes would fail to develop. One of the few exceptions is a zygote with an extra copy of chromosome 21 (Figure 18.24). This condition is known as Down syndrome.

Figure 18.25 shows how an offspring of two normal parents might get an extra copy of chromosome 21.

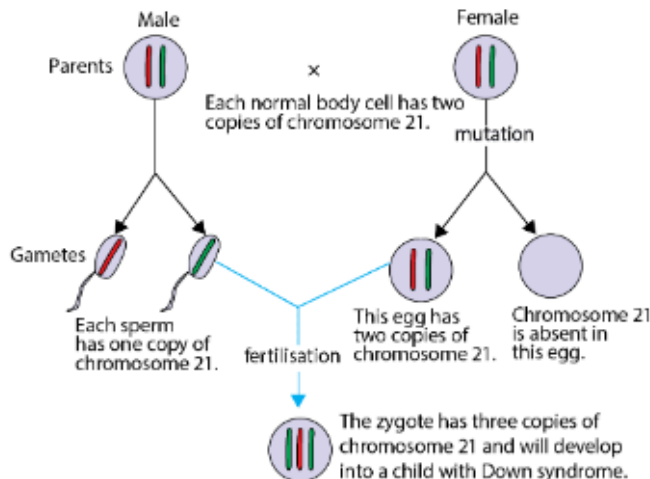


Figure 18.25 How two normal parents can produce a child with Down syndrome

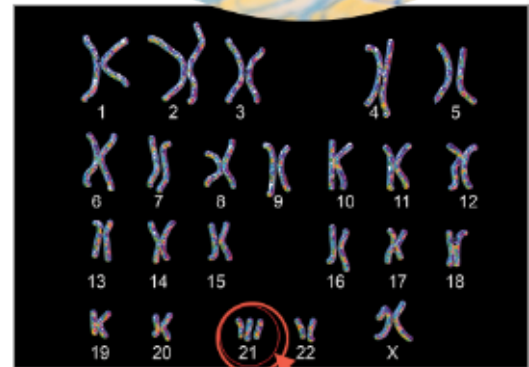
The older the mother, the higher the chances that copies of chromosome 21 will not separate during gamete formation. It is also possible for mutation to occur in sperm, resulting in sperm that carry an extra chromosome 21.

Mutagens

The rate of **spontaneous** mutation is usually very low. However, the rate of mutation is greatly increased with the presence of certain agents in the external environment. Such mutagenic agents are called **mutagens**. Ionising radiation such as ultraviolet light, and alpha, beta and gamma radiations are mutagenic. Some chemicals, if present in certain concentrations, are mutagenic. Examples of chemical mutagens are tar and formaldehyde (in cigarette smoke), and a drug called lysergic acid diethylamide (LSD).

Let's Practise 18.5

- 1 (a) What is meant by the term *variation*?
- (b) Give **two** examples of genetic variation in humans.
- 2 (a) What is the meaning of *mutation*?
- (b) Give **two** examples of gene mutation and **one** example of chromosome mutation.



One extra chromosome 21 in a female with Down syndrome

Figure 18.24 People with Down syndrome have three instead of two copies of chromosome 21.



Word Alert

Spontaneous: sudden and random



Link

Theory Workbook
Worksheet 18E

18.6 What Is Natural Selection?

Learning Outcomes

- State that variation and competition lead to differential survival of, and reproduction by, those organisms best fitted to the environment.
- Give examples of environmental factors that act as forces of natural selection.
- Explain the role of natural selection as a possible mechanism for evolution which is a gradual change in the inheritable characteristics of a population over time.



Helpful Note

Although mutation is the ultimate source of variation, the appearance and distribution of the varieties in a population depend on fertilisation and meiosis.

You have learnt that variations in organisms may arise due to mutation. Competition for food and space occurs among these different varieties of organisms. Those varieties that are more competitive, more resistant to diseases and better adapted to changes in the environment can survive and reproduce better. The other varieties that are susceptible to diseases or environmental changes may die. This process is called *natural selection*.

► **Natural selection** refers to a process in which organisms with desirable genes and characteristics are 'selected' or 'favoured' to survive and pass on their genes to their offspring.

Mutation provides new genes or alleles (variations) for natural selection to operate on. After thousands or millions of years, more beneficial qualities (genes or alleles) may accumulate in a species. The new breed of organisms may be better adapted to their new environment. They may even change so much that they become a new species which differs from the original species.



Helpful Note

Organisms from the same species can breed and produce healthy, fertile offspring. If organisms from two populations cannot interbreed to produce fertile offspring, they are said to belong to two different species.

How Natural Selection Drives Evolution

The present complex forms of living organisms have arisen from simpler ancestral forms through a process called evolution. 'The Theory of Evolution by Natural Selection' was put forward by the English naturalists, Charles Darwin and Alfred Russel Wallace. The theory sought to explain how new species come about, resulting in the diverse living organisms we see around us.

► The gradual change in the inheritable characteristics of a population over time is called **evolution**.

Figure 18.26 shows a theoretical representation of how mutation, competition and natural selection can lead to evolution.



Disciplinary Idea

Evolution

Environmental change and competition for resources are driving forces for survival.

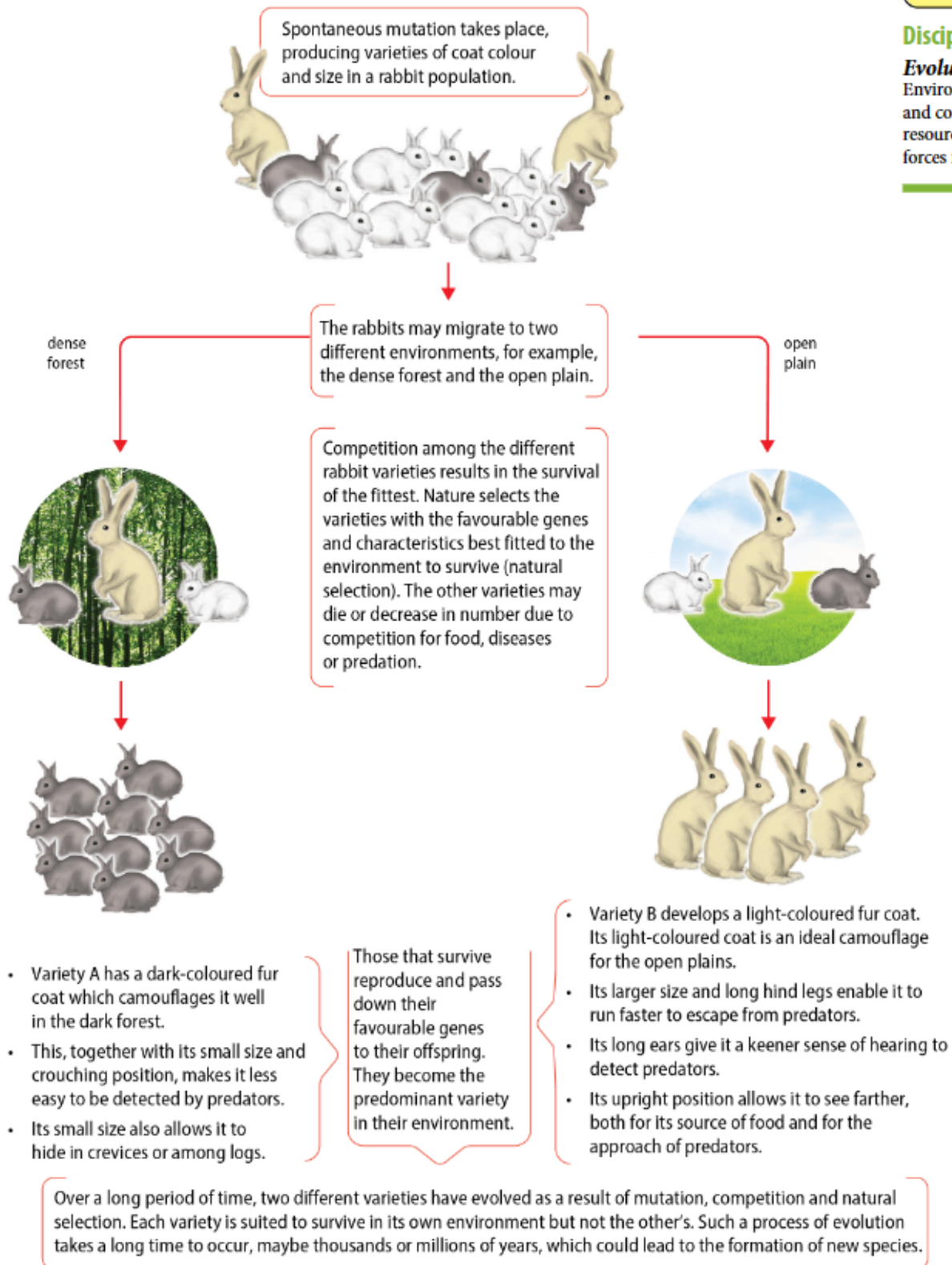


Figure 18.26 A theoretical example of how evolution could occur



Disciplinary Idea

Evolution

Evolution by natural selection is the gradual change in the inheritable characteristics in a population over time.



Here is a summary of evolution by natural selection:

- **Variation and competition for survival**

Organisms have great reproductive potential. They produce more offspring than can survive. Organisms die because of environmental factors such as **competition** for food, diseases and being eaten up by predators. Mutations cause organisms to show **variation**, i.e. differences in characteristics. Variation and competition lead to differential survival and reproduction by those organisms best fitted to the environment.

- **Survival of the fittest**

Organisms with favourable genes and characteristics that make them better adapted to the environmental conditions are most likely to survive. This is called **survival of the fittest**.

- **Reproduction and passing down favourable genes**

Organisms that survive reproduce and pass down their favourable genes to their offspring. Over time, more beneficial qualities (genes or alleles) may accumulate in a species. The new breed of organisms may be better adapted to their new environment. They may even change so much that they become a new species which differs from the original species from which they have evolved.

Examples of Natural Selection

Dark Peppered Moths

In 1848, the dark peppered moth was a rare sighting in England. By 1900, dark peppered moths became very common in the country. What was happening to cause this phenomenon?

During that period, England was experiencing industrialisation. Many factories that were built used coal for fuel. The burning of coal produced dark smoke that covered the environment. As a result, the trunks of the trees were covered with soot from the smoke.

Scientists found that dark peppered moths were able to **camouflage** better on the blackened tree trunks compared to light peppered moths. They avoided being eaten and had more time to reproduce. Over time, the population of dark peppered moths increased due to natural selection.



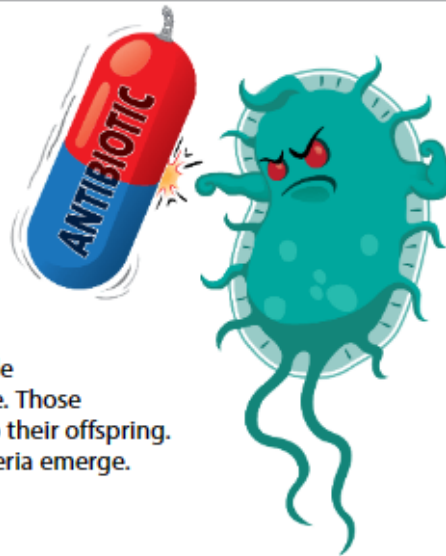
Word Alert

Camouflage: blend in with the surroundings



Antibiotic-resistant Strains of Bacteria

Indiscriminate use of antibiotics has led to the evolution of bacteria that are resistant to certain types of antibiotics. Genetic variations occur in bacteria because of mutation. Bacteria with mutation that give them resistance against antibiotics will survive, while those without this mutation will die. Those that survive will pass their alleles to their offspring. Over time, antibiotic-resistant bacteria emerge.



Link

Recall what you have learnt in Chapter 11 about antibiotic resistance in bacteria.

Darwin's Finches

Evidence for natural selection is seen in Darwin's finches on the Galapagos Islands. On the South American mainland, finches have short, straight beaks to crush seeds. On the Galapagos Islands there are six major types of beaks, each suited to a particular diet.



Cool Career

Naturalist

Charles Darwin was an English naturalist who proposed the theory of evolution by natural selection. He was in his second year of medical school when he decided to change his course of study and pursue his passion in natural sciences. He went on a five-year voyage on a ship, the HMS Beagle. During the voyage, he developed the ground-breaking theory of evolution through his keen observations of the environment around him.

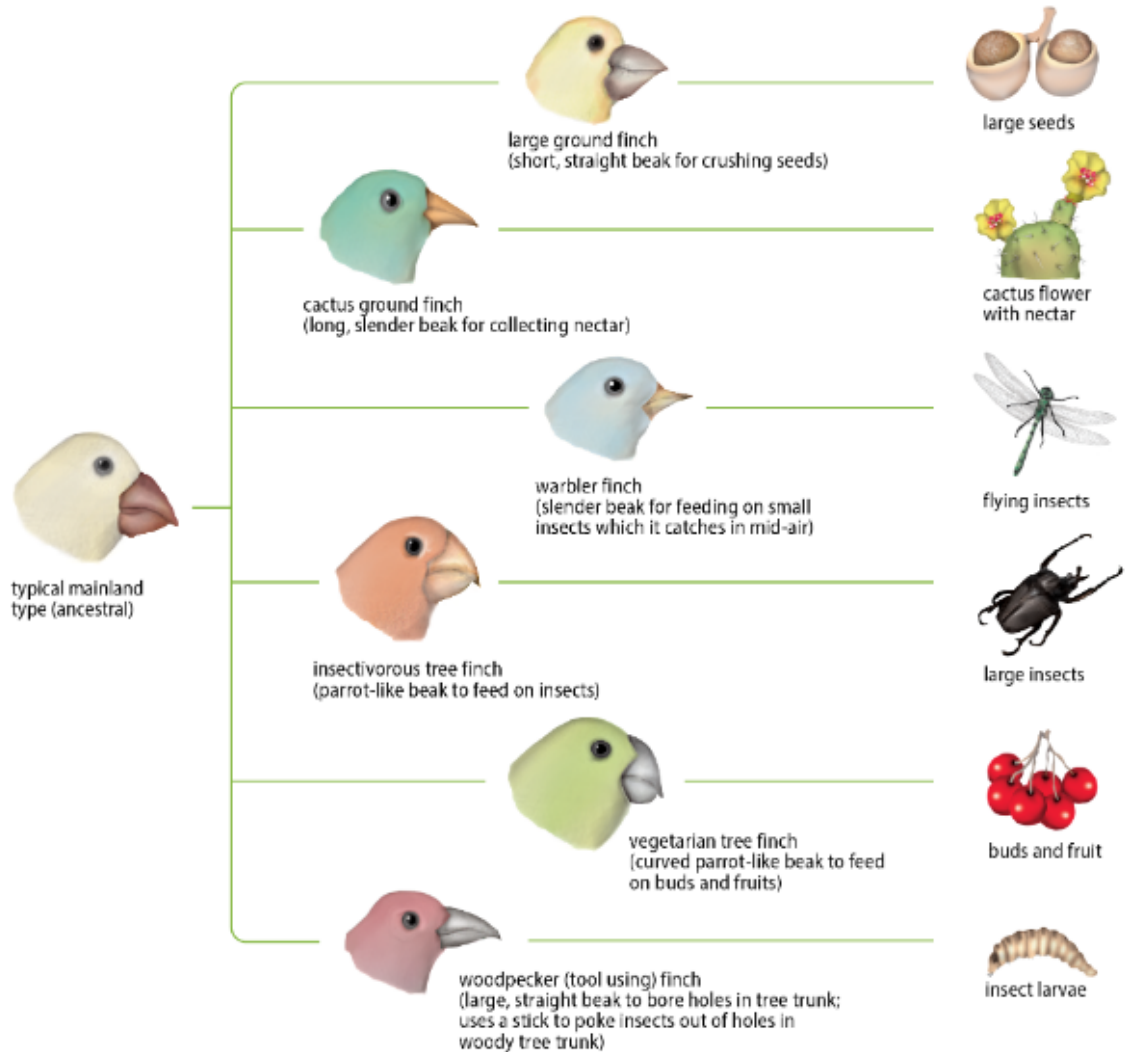
Do you have a passion like Charles Darwin to be a naturalist?

In today's modern context, the job of a naturalist may involve several areas. These include protecting, preserving, maintaining and restoring wildlife and natural habitats. To do all these, a naturalist also needs to play one important role, that is, to educate the public about our natural environment.



Figure 18.27 A naturalist involved in conserving turtles and their habitat

The beaks of six finches are shown in Figure 18.28.



Darwin's explanation:

- ① Darwin's explanation is that ancestral finches from the mainland managed to get to the islands.
- ② Once separated, the island finches began to evolve along different lines from the mainland finches.
- ③ The island finches reproduced rapidly and competition arose. There was a struggle for existence.
- ④ Variations occurred among the finches. Natural selection began to take place.
- ⑤ Those finches with beaks suited to a particular diet on the islands survived and reproduced.
- ⑥ Eventually six major types of finches evolved, each of which was adapted to a particular food source such as seeds, fruits and insects.

Figure 18.28 How the different varieties of finches on Galapagos Islands evolved according to Darwin

In the example of the Galapagos finches, one common ancestor had evolved into several different species of finches, each adapted to a particular diet. Such a process is called adaptive radiation.

Darwin's explanation on the finches in Galapagos island provides evidence for the role of natural selection as a possible mechanism for evolution.

Let's Practise 18.6

- 1 What is meant by the term *natural selection*?
- 2 State **two** factors that can give rise to the survival of organisms that are best fitted to the environment.



Disciplinary Idea

Evolution

Adaptive traits (structural or behavioural) and changes in environmental conditions can affect the survival of organisms.



Link

Theory Workbook

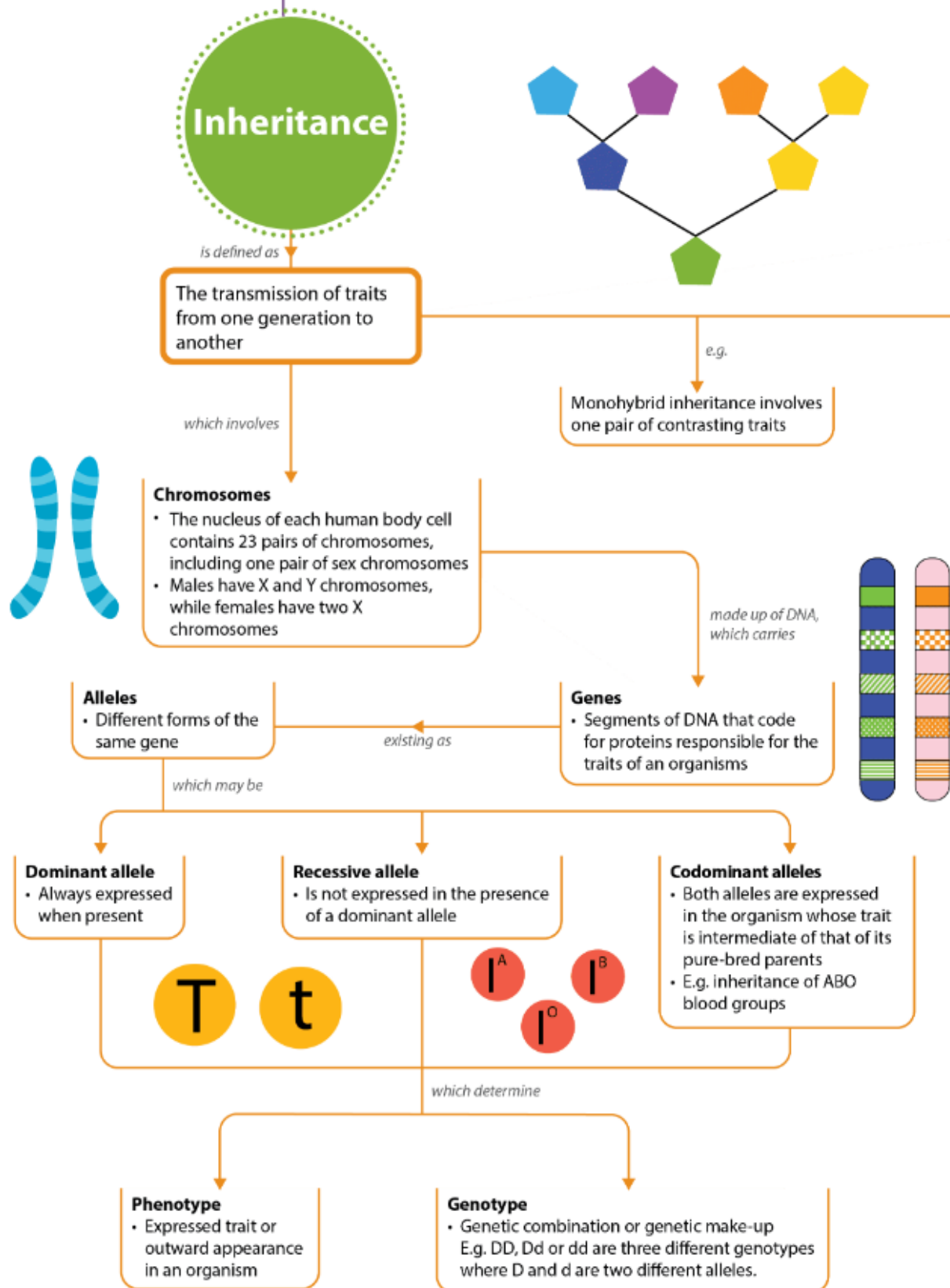
Worksheet 18F

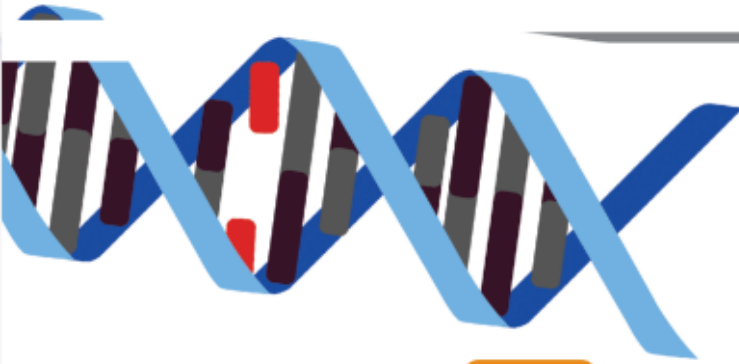
Let's Assess

Let's Reflect



Let's Map It





Variation

is caused by

Sources of genetic variation

- Meiosis
- Random fertilisation
- Mutation
 - rate increased by ionising radiation (e.g. UV light) and chemical mutagens (e.g. tar)
 - results in conditions such as albinism, sickle cell anaemia and Down syndrome



involves



contributed to

Natural selection

- Occurs when environmental conditions change
- Selects organisms with desirable alleles and traits to survive and pass on their alleles to their offspring
- Selection is for the benefit and survival of the organisms

is defined as

The differences in traits between individuals of the same species



as either

Discontinuous variation

- Few clear-cut phenotypes
- Controlled by one or a few genes
- Genes do not show additive effect
- Environment has little or no effect
- E.g. ABO blood groups, single or double eyelids, and tongue rolling



Continuous variation

- A range of phenotypes
- Controlled by many genes
- Genes show additive effect
- Environment has a great effect on the phenotypes
- E.g. human height, body type and skin colour

leads to



Evolution

- The gradual change in the inheritable characteristics of a population over time



Let's Review

Section A: Multiple-choice Questions

Refer to the text below to answer questions 1 and 2.

Huntington's disease is a rare lethal brain disease. It is caused by a dominant allele. The allele is normally not expressed until middle age. Once expressed, death will follow within a few years. Figure 18.29 shows a family tree of an affected family. The current age of the family members are shown in brackets.

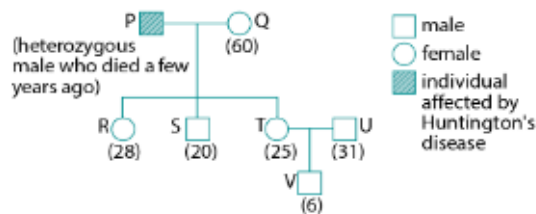


Figure 18.29

1 What is the probability that T will develop the disease?

- ☐ A 25%
- ☐ B 50%
- ☐ C 75%
- ☐ D 100%

2 Using your answer in 1, and assuming U is homozygous recessive, which of the following is **true** about V?

- ☐ A V may have the same genotype as T.
- ☐ B V may be homozygous dominant for the disease.
- ☐ C V can never be homozygous recessive for the disease.
- ☐ D The probability that V will not develop the disease is zero.

3 What determines the sex of a child?

- ☐ A chromosome content of the ovum
- ☐ B chromosome content of the sperm
- ☐ C number of days between ovulation and implantation
- ☐ D number of days between menstruation and ovulation

4 Fruit flies have normal red eyes. When some fruit flies are subjected to radiation in the laboratory, they produced offspring with white eyes. This is an example of _____

- ☐ A codominance
- ☐ B natural selection
- ☐ C monohybrid inheritance
- ☐ D mutation

5 The thickness of the shells of some snails is controlled by two alleles as shown below:

- AA have thick shells
- AB have thin shells
- BB do not survive

Two heterozygous snails are mated. What is the probability that a surviving snail of the next generation is a heterozygote?

- ☐ A 0
- ☐ B 0.25
- ☐ C 0.5
- ☐ D 0.67

6 Which of the following statements is **true** of a dominant gene?

- ☐ A It gives the organism a better chance of survival than a recessive gene.
- ☐ B It does not undergo mutation.
- ☐ C It is expressed in both the homozygous and heterozygous conditions.
- ☐ D It is not expressed in the heterozygous condition.

7 Which two characteristics both show discontinuous variation?

- ☐ A blood group, tongue rolling
- ☐ B body type, tongue rolling
- ☐ C eye colour, skin colour
- ☐ D eye colour, height

- 8 Farmers have noticed that, over the years, the amount of pesticide required to act against caterpillars increases. What is the best explanation for this observation?



- ☐ A Most of the caterpillars become more resistant due to repeated exposure to the pesticide.
- ☐ B Most of the caterpillars mutate at every generation and become resistant.
- ☐ C Some of the caterpillars that are already resistant survive. They are able to reproduce and pass this resistance trait to the next generation.
- ☐ D The allele that gives rise to resistance become dominant over the years due to selection.

Section B: Structured Questions

- 1 Coat colour in rabbits is controlled by the following alleles:
 C — allele for normal coat (grey)
 c^h — allele for Himalayan coat
 c^a — allele for albino
 C is dominant to both c^h and c^a , while c^h is dominant to c^a .

A rabbit breeder suspects that one of his normal coat rabbits is not homozygous.

- (a) What would you advise him to do in order to find out the genotype of the rabbit?
- (b) What results would you expect? Explain your answer by means of genetic diagrams.
- 2 Normal skin pigmentation is caused by a dominant allele A. Albinism is homozygous recessive (aa). What are the chances of getting an albino from the following crosses?
- (a) $Aa \times aa$
 (b) $Aa \times Aa$
 (c) $aa \times aa$
 (d) $AA \times aa$

Section C: Free-response Question

- 1 Explain the role of mutation and natural selection in evolution.



Link

Theory Workbook
Revision Worksheet 4

Answer Key

Chapter 1: Cell Structure and Organisation

Let's Investigate 1.1

- 1 The ribosomes, vacuole and mitochondria are not visible under the light microscope.
- 2 To prevent air bubbles from forming

Let's Investigate 1.2

- 1 This cell does not contain chloroplasts. The chromosomes and mitochondria are not visible under the light microscope.
- 2 Plant cells contain cell walls but animal cells do not. Animal cells are more irregular in shape than plant cells. Plant cells contain chloroplasts but not animal cells. (Any two)

Let's Practise 1.1

- 1 (a) Chloroplasts are sites for photosynthesis.
(b) Golgi body secretes substances made by the ER out of the cell and stores and modifies substances for secretion.
(c) Mitochondria are needed for aerobic respiration to ensure the release of energy for cell activities.
(d) Ribosomes are involved in protein synthesis.
(e) Rough ER transports proteins from the ribosomes to the Golgi body for secretion out of the cell.
(f) Smooth ER is involved in producing fats and steroids and in detoxification.
(g) Vacuoles store food substances and water.
- 2 Cell wall is present in a plant cell but not in an animal cell. Chloroplasts are present in a plant cell but not in an animal cell. A plant cell has a large central vacuole but an animal cell has many small vacuoles.
- 3 (a) A: cell membrane; B: cytoplasm; C: nucleus
(b) Animal cell. It does not have a cellulose cell wall, a large central vacuole or chloroplasts

Let's Practise 1.2

Important Characteristic(s) to Serve Its Function Well	How These Characteristics Help It to Perform Its Functions
Long narrow extension	Long and narrow structure increases surface area-to-volume ratio so that water and mineral salts can be efficiently absorbed from the soil
- Contains haemoglobin - Circular biconcave shape - Does not have a nucleus	- Contains the pigment haemoglobin which binds with oxygen and transports it from the lungs to all parts of the body - Circular, biconcave shape increases surface area-to-volume ratio so that oxygen can diffuse into and out of the whole cell at a higher rate - Enables the cell to store more haemoglobin for transport of oxygen

Let's Review

Section A: Multiple-choice Questions

- 1 D 2 C

Section B: Structured Questions

- 1 (a) Cell membrane (b) Nucleus
(c) Mitochondrion (d) Golgi body
- 2 (a) Cell membrane, cytoplasm, nucleus, mitochondria, endoplasmic reticulum, Golgi body, ribosomes
(b) Chloroplasts, large central vacuole
- 3 A. Presence of cell wall

Section C: Free-response Question

- 1 Refer to 'Rough Endoplasmic Reticulum' and Figure 1.13 in Section 1.1.

Chapter 2: Movement of Substances

Let's Investigate 2.1

- 1 The copper sulfate crystal dissolves in the water, forming a deep blue solution at the bottom of the glass jar. Then the blue colour gradually spreads upwards through the water until all the liquid in the gas jar is in the same shade of pale blue. The dissolved copper sulfate particles diffuse from the bottom of the gas jar where they are more concentrated, upwards to other regions where they are in lower concentration or where they are absent.
- 2 Diffusion stops when the copper sulfate particles are evenly distributed throughout the liquid.

Let's Investigate 2.2

Surface area	6 cm ²	24 cm ²	54 cm ²
Volume	1 cm ³	8 cm ³	27 cm ³
Surface area-to-volume ratio	6 : 1	3 : 1	2 : 1

Let's Investigate 2.3

- 1 With the same volume, the larger the surface area, the higher the rate of absorption of the acid.
- 2 Cells in the body with an absorptive or transport function should have the shape of agar block C, which has the largest surface area-to-volume ratio among the three agar blocks. This increases the rate of substances entering or leaving the cells.

Let's Practise 2.1

- 1 (a) Difference in the concentration of a particular substance between two regions
(b) Diffusion is the net movement of particles (atoms, molecules or ions) from a region of their higher concentration to a region of their lower concentration (down a concentration gradient). Steepness of the concentration gradient for a substance, temperature, diffusion distance, surface area-to-volume ratio.
- 2 Small cells have a large surface area-to-volume ratio, hence they are able to obtain sufficient food and oxygen per unit time for their growth needs. They are also able to remove waste products at a faster rate than larger cells. They do not grow beyond a certain size to maintain a large surface area-to-volume ratio for optimum absorption and removal of materials.
- 3 (a) The root hair cell has a long tube-like protrusion (root hair). The epithelial cell has many microvilli. The red blood cell has a flattened, biconcave shape. These features increase the surface area available for the absorption of materials.
(b) A large surface area-to-volume ratio

Let's Investigate 2.4

- 1 The dialysis tubing is partially permeable. In the first experiment, the water potential of the distilled water in the boiling tube is higher than that of the sucrose solution in the tubing. Therefore, water molecules enter the tubing by osmosis. In the second experiment, the water potential inside and outside the tubing is the same. Therefore, there is no net movement of water molecules.
- 2 The second experimental set-up acts as a control as the water potential is the same both inside and outside the partially permeable membrane and no movement of water molecules will take place.

Let's Investigate 2.5

Refer to Experiment 2C of the Practical Workbook. When the surrounding solution has a lower water potential than the cell sap, water molecules leave the cells by osmosis. The cells shrink and become plasmolysed. The potato strip thus becomes flaccid and smooth. Conversely, when the cell sap of the potato strip has a lower water potential than the surrounding solution, water molecules enter the cells by osmosis. The cells increase in size and the potato strip becomes turgid and rough.

Extension to experiment to estimate the concentration of cell sap in the cell:

Step 1: Prepare five solutions of varying concentrations of sucrose (e.g. 10%, 5%, 2%, 1%, 0%).

Step 2: Put three identical cylinders of fresh potato in each sucrose solution. After 30 minutes, record the average change in length or mass.

Step 3: Plot a graph of average change in length or mass against concentration of sucrose solution. The concentration of the cell sap of the potato cells can be determined from the x-intercept. At this point, there is no change in the length/mass of the potato cylinder as there is no net movement of water into or out of the potato cells. That is because the cell sap has the same water potential as the sucrose solution.

Let's Investigate 2.6

Refer to Experiment 2D of the Practical Workbook.

Strip in water curls outwards. Cell sap of the strip has lower water potential than the surrounding water. Hence, water enters the cells by osmosis. However, the epidermal cells are prevented from stretching by the inelastic cuticle layer. Thus, only the inner cells (cortex) expand, causing the strip to curl outwards.

Strip in strong sucrose solution curls inwards. Cell sap of the strip has higher water potential than the sucrose solution. Hence, water leaves the cells by osmosis. However, the cuticle protects the epidermal cells against water loss. Thus, only the inner cells (cortex) shrink, causing the strip to curl inwards.

Let's Investigate 2.7

- 3 Cut the spinach stem lengthwise into four strips. Place one strip in each of the three solutions for 20 minutes.
- 4, 5 The strip in the very concentrated solution will be bent with the epidermis on the outer (longer) side. The strip in the dilute solution will be slightly bent with the epidermis on the inner (shorter) side. The strip in the very dilute solution will be very bent with the epidermis on the inner (shorter) side.
- 6 If the solution has a lower water potential than the cell sap, water molecules leave the cells by osmosis. The cells near the inner surface of the stem become flaccid and shrink more than cells in the epidermis, which is protected by a waterproof cuticle. If the solution has the same water potential as the cell sap, there is no net movement of water molecules. If the solution has a higher water potential than the cell sap, water molecules enter the cells by osmosis. The cells become turgid and expand. The cells near the inner surface of the stem become turgid and expand more than the cells in the epidermis.

Let's Practise 2.2

- 1 Brine or syrups have a higher concentration of salt or sugar than the cytoplasm in bacteria and fungi that get into food. These solutions have a lower water potential than the cytoplasm in these microorganisms. Thus, the microorganisms will rapidly lose water by osmosis and die, preventing them from turning the food bad.
- 2 Water molecules will leave the cell, sugar molecules will enter the cell. Osmosis and diffusion.

Let's Practise 2.3

- 1 Dead cells do not respire. Active transport requires energy released from respiration.
- 2 Refer to Table 2.3 in Section 2.3.

Let's Review

Section A: Multiple-choice Questions

- 1 C 2 B

Section B: Structured Question

- 1 X, Y, Z

Section C: Free-response Questions

- 1 Diffusion is the net movement of particles (atoms, molecules or ions) from a region where they are of higher concentration to a region where they are of lower concentration (down a concentration gradient).
Osmosis is the movement of water molecules from a region of higher water potential to a region of lower water potential, through a partially permeable membrane.
A partially permeable membrane is a membrane that allows certain substances to pass through.
- 2 Diffusion involves the movement of particles of any substance, gaseous or liquid, whereas osmosis involves movement of water molecules only. In addition, osmosis takes place across a partially permeable membrane whereas diffusion does not require a partially permeable membrane.
- 3 During sports, your body loses water and essential salts to the environment through sweating. These essential salts and water can be replaced by the sports drink that you drink. Sports drinks have the same water potential as the fluid in the cells of your body so that there is no net movement of water into or out of cells. The cells will not absorb water and swell nor will they lose water and dehydrate.

Chapter 3: Biological Molecules

Let's Practise 3.1

- 1 Refer to Let's Investigate 3.1.
- 2 Refer to Let's Investigate 3.2.
- 3 Refer to 'What are the functions of carbohydrates?' in Section 3.1.
- 4 A red precipitate would be produced, showing the presence of reducing sugars. The starch has been digested to maltose by amylase.

Let's Practise 3.2

- 1 Carbon, hydrogen and oxygen
- 2 Refer to 'What are the functions of fats?' in Section 3.2.
- 3 Refer to Let's Investigate 3.3.

Answer Key

Let's Investigate 3.4

Violet or deep purple colouration appears. This indicates the presence of proteins.

Let's Practise 3.3

- (a) Carbon, hydrogen, oxygen, nitrogen and maybe sulfur
(b) Refer to 'What are the functions of proteins?' in Section 3.3.
- Refer to Let's Investigate 3.4.
- (a) A: reducing sugar, B: reducing sugar and protein, C: starch and protein
(b) Cut the orange skin into small bits. Place them in a test-tube and add 2 cm³ of ethanol. Shake the mixture and decant the liquid into a test-tube containing a 2 cm³ of water and shake the mixture. A white emulsion indicates fats are present. If the solution remains clear, fats are absent.
(c) Refer to 'What are the functions of proteins?' in Section 3.4.

Let's Review

Section A: Multiple-choice Questions

1 A 2 C 3 C

Section B: Structured Questions

- (a) Fats
(b) Fats are used as long-term storage and insulation because they have a higher energy value than carbohydrates.
- (a) Carbohydrates: carbon, hydrogen, oxygen
Proteins: Carbon, hydrogen, oxygen, nitrogen (sulfur may be present)
(b) (i) Glucose (ii) Glucose (iii) Amino acids
(iv) Fatty acids, glycerol
(c) (i) Refer to 'What are the functions of carbohydrates?' in Section 3.1.
(ii) Refer to 'What are the functions of fats?' in Section 3.2.
(iii) Refer to 'What are the functions of proteins?' in Section 3.3.

Section C: Free-response Question

- Bananas contain carbohydrates which provide energy to the player during the game.

Chapter 4: Enzymes

Let's Practise 4.1

- (a) An enzyme is a biological catalyst made of protein. It alters the rate of a chemical reaction without itself being chemically changed at the end of the reaction.
(b) Enzymes catalyse reactions that build up complex substances or break down complex substances.
- (a) Meat contains mostly proteins, hence we can infer that this enzyme acts on proteins.
(b) The enzyme could soften meat by breaking down some of the large protein molecules into smaller molecules.
- Water and oxygen are produced when catalase in the red blood cells breaks down hydrogen peroxide. The production of oxygen results in the foam observed.

Let's Investigate 4.1

At very low temperatures, amylase is inactive. The activity of amylase increases as the temperature increases. However, beyond a certain optimum temperature, enzyme activity decreases. Amylase is denatured at very high temperatures.

Let's Investigate 4.2

- Protease is active in test-tube A and the egg white in this test-tube will be digested and turn clear.
- Test-tube B is a control. It shows that it is the protease that digested the egg white protein. Test-tube D shows that protease is denatured in neutral conditions.

Let's Practise 4.2

- (a) Enzymes are specific in action; enzymes remain unchanged at the end of the reaction
(b) Enzymes are required in minute amounts; enzyme reactions are affected by the temperature/pH of the solution; enzymes remain chemically unchanged at the end of a reaction
- Refer to definition of denaturation in Section 4.2.

Let's Review

Section A: Multiple-choice Questions

1 C 2 A

Section B: Structured Questions

- Enzyme specificity is due to their three-dimensional shape or surface configuration. Each enzyme has an active site. Only substrate with shape complementary to that of the active site can fit into the active site to form an enzyme-substrate complex, just like how a key fits into a lock.
- Any three of the following characteristics: Enzymes speed up chemical reactions; Enzymes are specific in their action; Enzymes are affected by temperature; Enzymes are affected by pH; Enzymes catalyse reversible reactions; Enzymes are required in minute amounts; Enzymes remain chemically unchanged at the end of a reaction.
- (a) The enzymes would digest the proteins and fats, turning them into smaller molecules such as amino acids, fatty acids and glycerol, which can then be removed from clothes.
(b) The enzymes would be denatured at higher temperatures (higher than 45 °C).
(c) The enzymes from the bacteria in hot springs work at high temperatures, i.e., they are not denatured at higher temperatures of 70–80 °C. Using the enzymes from these bacteria would enable the production of biological washing powders that work effectively at high temperatures.

Section C: Free-response Questions

- Refer to 'Lock-and-key hypothesis' in Section 4.2.
- Refer to 'Enzymes are affected by temperature' in Section 4.2.

Chapter 5: Nutrition in Humans

Let's Practise 5.1

- Circular muscles contract, longitudinal muscles relax
- Circular muscles relax, longitudinal muscles contract
- Arrow should point to your left (when you face your drawing)

Let's Investigate 5.2

- Bile 2 The sulfur powder sank into the water.
- Bile emulsifies fat

Let's Practise 5.2

- If protease were produced in the active form, it would digest the proteins in the cells that produce it.
- (a) The stomach, pancreas and small intestine
(b) Amino acids

- 3 salivary gland and pancreas
- 4 (a) The liver produces bile and it is stored in the gall bladder.
(b) Bile emulsifies fat.

Let's Practise 5.3

- 1 Glucose and amino acids are absorbed by diffusion and active transport. Absorption takes place both in the presence and absence of oxygen, indicating diffusion. However, absorption is greater in the presence of oxygen, indicating active transport is also involved. The energy required for active transport is obtained from cell tissue (aerobic) respiration.
Glycerol and fatty acids are absorbed by diffusion only. Absorption is about the same under both aerobic and anaerobic conditions.
- 2 Too little water being reabsorbed from faeces in the small and large intestines.
- 3 Refer to the section 'How Is the Small Intestine Adapted for Absorption?' in Section 5.3.

Let's Investigate 5.3

- 1 (a) The starch molecules are too large and cannot pass through the gut wall. Starch is digested by the enzyme, amylase. Then maltose is digested by maltase. The small molecules of glucose can then pass through the gut wall and be absorbed into the blood.
(b) From the pancreas: amylase, from the small intestine: maltase
(c) The blood

Let's Practise 5.4

- 1 Transports nutrients from the small intestine to the liver
- 2 Lacteals in the intestinal villi.
- 3 Adipose tissue consists of fat cells. Adipose tissues formed around organs help to protect the organs from mechanical injury while adipose tissues formed in the skin prevent excessive heat loss. Fat in adipose tissues can also be broken down to release energy for cellular activities.
- 4 Refer to 'Production of bile' in Section 5.4.
- 5 Role of the liver in carbohydrate metabolism: Refer to 'Regulation of blood glucose concentration' in Section 5.4. Role of the liver in detoxification: Refer to 'Detoxification' in Section 5.4.

Let's Practise 5.5

- 1 Refer to 'Harmful Effects on the Digestive System' and 'Harmful Effects on the Nervous System' in Section 5.5.
- 2 Refer to 'Social Implications' in Section 5.5.

Let's Review

Section A: Multiple-choice Questions

- 1 B 2 D

Section B: Structured Questions

- 1 (a) (i) C (ii) A
(b) Intestinal enzymes work best in alkaline conditions while stomach enzymes work best in acidic conditions (hydrochloric acid in the stomach has pH = 2)
- 2 It gives time for the enzyme in papaya to break down some of the proteins in the meat. During cooking, the high temperature will denature the enzymes.
- 3 (a) A: small intestine; B: hepatic portal vein; C: liver (b) B will contain a higher concentration of glucose and amino acids

Section C: Free-response Question

- 1 Alcohol slows down brain functions. Excessive drinking of alcohol results in alcohol intoxication. Intoxication results in blurred vision, poor muscular coordination and slower reflexes. A motorist tends to underestimate speed and has a slower reaction time. With these effects, drunk motorists are more likely to cause accidents.

Chapter 6: Transport in Humans

Let's Investigate 6.1

- 1 A red blood cell has no nucleus and is biconcave in shape. White blood cells have a nucleus and is irregular in shape.
- 2 Red blood cells transport oxygen to all parts of the body. White blood cells help the body to fight infections by performing phagocytosis or producing antibodies.

Let's Practise 6.1

- 1 (a) To transport oxygen from the lungs to the other parts of the body (haemoglobin binds to oxygen in the lungs where oxygen concentration is high and releases oxygen in tissues where oxygen concentration is low)
(b) To bring about blood clotting when tissue is damaged
- 2 To produce antibodies that destroy disease-causing organisms and to engulf and destroy foreign particles such as bacteria
- 3 (a) Its biconcave shape increases the surface area-to-volume ratio. This increases the rate of absorption and release of oxygen.
(b) A thin membrane provides a short diffusion distance for oxygen, ensuring a higher rate of diffusion
(c) Being flexible allows the red blood cell to change into a bell-shaped structure so that it can flow easily through narrow blood capillaries.
- 4 Any organ from another person may be treated as a foreign body by the recipient's immune system. The recipient's white blood cells may respond by producing antibodies to destroy the transplanted organ.

Let's Practise 6.2

- 1 A, B, AB, O
- 2 The red blood cells of a person with blood group O do not possess antigens A and B. Hence, the red blood cells will not react with antibodies a or b, and will not cause agglutination when mixed with blood of other blood groups. Thus, a person with blood group O is a universal donor because his blood is compatible with that of other blood groups.

Let's Practise 6.3

- 1 Arteries, veins, capillaries
- 2 Arteries receive blood directly from the heart. They need to be able to withstand the immense pressure of the blood as it is forced out of the heart.
- 3 To prevent backflow of blood, as blood pressure in the veins is low.
- 4 Useful substances are transported from the blood to tissue cells via tissue fluid. Waste products from tissue cells are transported to the blood via tissue fluid for removal.
- 5 (a) There was a valve at C which prevented the blood from flowing back beyond C.
(b) The valve at C prevented the blood from flowing back to B.
(c) Valves in veins prevent the backflow of blood.

Answer Key

Let's Investigate 6.3

- (a) During physical exercise, more energy is needed for muscle contraction. This leads to an increase in aerobic respiration. The heart will have to beat faster so that oxygen and glucose can be transported more quickly to the muscles to meet the increase in demand. This also allows for the carbon dioxide produced to be transported quickly from the muscles to the lungs for removal.
(b) Student's answers may vary.
(c) Student's answers may vary.
- The higher the fitness level, the lower the pulse rate.

Let's Practise 6.4

- Thick and muscular walls, presence of valves
- Liver → hepatic vein → right atrium → tricuspid valve → right ventricle → pulmonary artery → lung
- This results in the mixing of oxygenated and deoxygenated blood, which causes less oxygen to be transported to the body cells for respiration. This may cause shortness of breath and fatigue, and in serious cases, heart failure.

Let's Practise 6.5

- Refer to 'What Are the Causes of Coronary Heart Disease?' in Section 6.5.
- Diet high in cholesterol or saturated fats, genetic factors, age, sedentary lifestyle (Any two)

Let's Review

Section A: Multiple-choice Questions

1 C 2 B 3 C 4 A 5 D

Section B: Structured Questions

- (a) A: Tissue fluid, B: Blood / blood plasma
(b) (i) Carbon dioxide (ii) Glucose or amino acids
(c) Blood capillary: the wall is one cell thick, the lumen is narrow as the red blood cells are arranged in a single file (or one after the other)
- (a) X belongs to group B, Y to group O, and Z to group AB.
(b) Antibody b in the plasma reacts with antigen B on the red blood cells, causing clumping of the red blood cells from X.
(c) Blood groups A, B, AB and O (d) Blood groups A and AB

Section C: Free-response Questions

- Blood may be infected with disease-causing microorganisms such as bacteria. The patient's body produces more white blood cells to combat the bacteria, i.e. to ingest bacteria and produce antibodies.
- Refer to 'What Is the Cardiac Cycle?' in Section 6.4.

Chapter 7: Respiration in Humans

Let's Investigate 7.1

Procedure (a)

- As potassium hydroxide solution absorbs carbon dioxide, it is used to remove carbon dioxide from air entering flask C. As limewater turns cloudy in the presence of carbon dioxide, it is used to confirm that air entering flask C is free of carbon dioxide.
- The limewater turns cloudy. The snails give off carbon dioxide as they respire.
- Remove the snails. / Make flask C empty.
- Keep the set-up in the dark or wrap flask C with a black material to prevent photosynthesis from taking place. Photosynthesis makes use of carbon dioxide which will render the results inaccurate.

Procedure (b)

- As carbon dioxide from the breath blown into the test-tube mixes with the solution, the hydrogencarbonate indicator changes colour. Carbon dioxide forms a slightly acidic solution and the colour of the indicator changes to yellow. No change is observed in the control.

Let's Investigate 7.2

- Boiling removes dissolved oxygen and carbon dioxide from the glucose solution. Oxygen must be removed because fermentation is an anaerobic process. Carbon dioxide must be removed so that it does not interfere with the results.
- The layer of oil prevents oxygen in the air from entering the yeast suspension, which prevents the yeast from carrying out aerobic respiration.
- Bubbles emerge from the end of the delivery tube. A white precipitate is produced in the limewater. Yeast releases carbon dioxide during anaerobic respiration.
- Everything would be the same except that boiled yeast suspension is used. The yeast suspension is boiled and then cooled before use.

Let's Practise 7.1

- Respiration releases energy for living organisms to carry out vital activities.
- (a) Aerobic respiration in humans:
Word equation: glucose + oxygen → carbon dioxide + water
Chemical equation: $C_6H_{12}O_6 + 6 O_2 \rightarrow 6 CO_2 + 6 H_2O$
(b) Anaerobic respiration in human cells:
Word equation: glucose → lactic acid
- Energy is required for pumping action of the heart / breathing movements / movement of gut muscles. (Any two)
- (a) The solution in tube A would turn yellow. The snail would respire and give out carbon dioxide, which is acidic. The solution in tube B would turn purple. The green plant would photosynthesise and remove carbon dioxide from the solution, making it more alkaline.
(b) Any carbon dioxide released by the snail is used up by the plant for photosynthesis. The rate of photosynthesis = rate of respiration in both organisms.
(c) No. The pH level of the solution does not change as there are no living organisms in the tube. Therefore, no colour change will be observed.
- (a) Rate of oxygen uptake (b) To absorb carbon dioxide
(c) To the left
(d) Oxygen in the boiling tube is taken in by the larva during inspiration. Carbon dioxide released by the larva during expiration is absorbed by the sodium hydroxide. Thus, the air pressure in the boiling tube drops and this will cause air pressure from outside to push the coloured droplet to the left.

Let's Practise 7.2

- Refer to Figure 7.8.
- (a) A: cell membrane, B: cytoplasm, C: nucleus
(b) Refer to Figure 7.9 (c) Mucus
(d) Dust trapped in the mucus lining the air passages cannot be removed.

Let's Investigate 7.3

- A white precipitate has formed in the limewater in flask B. The limewater in flask A remains clear.
- Expired air contains more carbon dioxide than inspired air.

Let's Investigate 7.4

- Expired air has a higher temperature than inspired air.

Let's Practise 7.3

- (a) 19 (b) 0.5 dm^3
(c) His breathing rate increased, and he took in and expelled more air per breath.
(d) B

Let's Practise 7.4

- (a) Nicotine, carbon monoxide, tar
(b) Refer to Figure 7.25.
- Refer to 'Chronic Bronchitis' in Section 7.5.

Let's Review

Section A: Multiple-choice Questions

- 1 A 2 B

Section B: Structured Questions

- (a) Both processes release energy. Both processes involve the breakdown of glucose.
(b) Aerobic respiration requires oxygen, while anaerobic respiration does not. A large amount of energy is released through aerobic respiration, while only a small amount of energy is released through anaerobic respiration. Carbon dioxide and water is produced through aerobic respiration, while lactic acid is produced through anaerobic respiration.
- (a) A lot of energy is required to produce the vigorous muscle contractions needed within a short period of time. Therefore, oxygen supply to the muscles is insufficient for aerobic respiration to meet the increased energy demand alone. The additional energy needed can be obtained through anaerobic respiration.
(b) Glucose $\rightarrow$ Lactic acid
- (a) A: bronchiole, B: blood capillaries, C: alveolus
(b) (i) more carbon dioxide in X as compared to Y
(ii) less oxygen in X as compared to Y

Section C: Free-response Questions

- Refer to 'In Muscle Cells' in Section 7.1.
- The following adaptations in the lungs ensure efficient absorption of oxygen:
 - The numerous alveoli in the lungs provide a large surface area.
 - The wall of the alveolus is only one-cell thick. This provides a short diffusion distance for gases, ensuring a higher rate of diffusion.
 - A thin film of moisture covers the inner surface of the alveolus. This allows oxygen to dissolve in it.
 - The walls of the alveoli are richly supplied with blood capillaries. The flow of blood maintains the concentration gradient of gases.
- Expired air has: less oxygen and more carbon dioxide because oxygen is taken in by the body cells and carbon dioxide is released; more water vapour as some water evaporates from the surfaces of the alveoli; a temperature around 37°C because it attains body temperature when within the body.
- This is because the partition walls between the alveoli breaks down and this reduces the surface area for gaseous exchange.

Chapter 8: Excretion in Humans

Let's Practise 8.1

- (a) (i) Metabolic waste products are substances produced from metabolic activities that are harmful or toxic to the body.

- (ii) Excretion is the removal of metabolic waste products, toxic substances and substances in excess of the body's requirements.
- (b) Exhalation which involves the excretion of carbon dioxide; Sweating/urination which involves the excretion of urea and excess mineral salts and water

Let's Practise 8.2

- (a) A: nephron, B: renal artery, C: renal vein, D: ureter
(b) To transport urine to the urinary bladder

Let's Practise 8.3

- (a) Platelets / Proteins (Accept other possible answers.)
(b) (i) Glucose and amino acids.
(ii) They are selectively reabsorbed by active transport in the nephron.
- The blood in A is oxygenated whereas the blood in B is deoxygenated. The blood in A has more urea than the blood in B.

Let's Practise 8.4

- A large amount of salt in the diet lowers the water potential of blood plasma. Tissue cells lose water to the blood. Blood volume increases, leading to a rise in blood pressure.
- (a) Alcohol reduces the production of ADH, causing the kidney tubules to reabsorb less water.
(b) The urine would be more dilute (less concentrated) and urine volume would increase.

Let's Practise 8.5

- (a) Urea molecules / mineral salts / water (Any two)
(b) Diffusion (urea molecules, mineral salts), osmosis (water)
(c) Blood cells / proteins (d) Partially permeable

Let's Review

Section A: Multiple-choice Questions

- 1 C 2 B

Section B: Structured Questions

- (a) Urea
(b) A decrease in blood pressure leads to a decrease in ultrafiltration rate. Waste products may accumulate in the person's blood if they are not removed fast enough.
- (a) A (Region 2), B (Region 1), C (Region 3)
(b) Region 1: The blood in the arteriole contains both reducing sugar, glucose and proteins.
Region 2: Ultrafiltration occurs in the glomerulus. Glucose molecules are small enough to pass out of the blood capillaries but not protein molecules.
Region 3: As the filtrate passes through the nephron, all the glucose are reabsorbed back into the bloodstream. Hence, the urine that leaves the kidney does not contain any glucose or protein.
- (a) Essential salts would diffuse out of the blood into the dialysis fluid.
(b) (i) The tubing is narrow, long and coiled to increase the surface area-to-volume ratio.
(ii) This speeds up the rate of exchange of substances between the blood and the dialysis fluid.
(c) (i) The opposite directions of flow maintain the diffusion gradient for the removal of waste products.
(ii) If the directions of flow were the same, the efficiency of removing metabolic waste products from the blood would be reduced.

Section C: Free-response Questions

- On a hot day, the rate of sweat production is increased. Loss of water in sweat lowers the water potential in the blood plasma. More ADH is secreted, making the collecting ducts in kidneys more permeable. More water is reabsorbed. Smaller volume of urine produced. Urine is also more concentrated.
 - On a cold day, sweat glands are less active. Less ADH is secreted, making the collecting ducts in kidneys less permeable. Less water is reabsorbed. Larger volume of urine produced. Urine is also more diluted.
 - Fall in blood pressure decreases rate of ultrafiltration in nephrons. Less filtrate is produced, leading to less urine being produced.
- Faeces is undigested material from the alimentary canal. The removal of faeces is called egestion. It is not produced from chemical activities taking place inside cells. Hence, it is not a metabolic waste product. Therefore, the removal of faeces is egestion and not excretion.

Chapter 9: Homeostasis and Hormonal Control

Let's Practise 9.1

- Homeostasis
- Refer to 'Regulation of blood glucose concentration' in Section 9.1.

Let's Practise 9.2

- Hormones are chemical substances that are produced in minute quantities by endocrine glands. They are transported by the blood and alter the activity of one or more target organs.
- An endocrine gland is a ductless gland that secretes its hormones directly into the bloodstream.
- insulin, glucagon
 - islets of Langerhans
- Refer to Figure 9.6
 - Diabetes mellitus*
 - A persistently high blood glucose level / Presence of glucose in the urine after a meal / Slow wound healing / Feeling thirsty most of the time / Weight loss / Fatigue (Any two)
 - Insulin injections into the body, avoid excessive intake of carbohydrates, especially sugars
- Refer to Figure 9.9.

Let's Investigate 9.1

- Cup B: When the water from the wet tissue paper evaporates, heat is removed from the cup, increasing heat loss.
- Room temperature
- On warm days, more sweat glands are active, resulting in more sweat being secreted. As water in the sweat evaporates, heat is removed, thus bringing about a decrease in temperature.

Let's Practise 9.3

- A: nerve ending (receptor), B: sweat gland, C: blood capillary
 - A: Detects pressure and temperature changes in the environment B: Secrete sweat C: Regulates body temperature by contraction and dilation
- Muscles in the skin arterioles cause the arterioles to dilate and constrict. When the arterioles dilate, the shunt vessels constrict and more blood flows to blood capillaries in the skin, increasing heat loss. When the arterioles constrict, the shunt vessels dilate and less blood flows to blood capillaries in the skin, decreasing heat loss.

- Gains heat: vigorous muscular exercise, eating hot food, be in warm environment (Any two)
 - Lose heat: by evaporation of water in sweat, through faeces and urine, through exhaled air (Any two)

Let's Review

Section A: Multiple-choice Questions

- 1 B 2 B 3 A 4 D

Section B: Structured Questions

- The person is performing physical activities.
 - The person has taken a sugary meal.
 - The production of hormone A is affected by the concentration of sugar in the blood.
 - They must not inject too much hormone A into the body. The injection needle used must also be sterilised.
- Insulin: pancreas; promotes utilisation of glucose by cells
ADH: pituitary gland; regulates water absorption into the bloodstream
- Blood vessels in the skin carry blood and heat to the skin surface. When they dilate, more blood and hence more heat is brought to the skin surface and lost to the surroundings. When they constrict, less heat is brought to the skin surface.
 - The hypothalamus in the brain monitors and regulates the body temperature. The hypothalamus receives information from temperature receptors in the skin about temperature changes in the external environment, and also monitors the temperature of blood passing through it. When activated, the hypothalamus sends out nerve impulses to relevant body parts to bring about changes to keep the body temperature constant.
 - When there is a significant drop in body temperature, the body muscles contract spasmodically, causing shivering. This increases heat production.

Section C: Free-response Questions

- The liver and muscle cells develop insulin resistance. They are unable to take in excess glucose in the blood.
 - Engaging in more physical activities, eating healthily, maintaining a healthy body weight based on your age and height.
- Alcohol consumed causes vasodilation; Skin arterioles dilate; More blood flows into skin capillaries; Blood carries heat from the deeper parts of the body to the skin; Heat is lost from the skin.

Chapter 10: The Nervous System and the Eye

Let's Practise 10.1

- A stimulus is a change in the environment. The body's reaction to the stimulus is the response. For example, when touching a hot object, the hand withdraws. The hot object is the stimulus, and the withdrawing of the hand is the response.
- Central nervous system consisting of the brain and spinal cord, peripheral nervous system consisting of the cranial and spinal nerves and sense organs (receptors)
- Sensory, relay and motor neurones
- Synapse
- An immediate response to a specific stimulus without conscious control.
- Endocrine system and nervous system. Refer to Table 10.1 in Section 10.1.

Let's Investigate 10.2

- Step 2: The pupil suddenly constricts and then enlarges slightly. In darkness, the pupil is wide open. Increase in light intensity causes the pupil to constrict. This prevents excessive light from entering the eye.
Step 3: At certain distances from the eye, the cross disappears from view. When the paper is moved farther away, the cross reappears. The dot is visible throughout.
The cross disappears from view because at a certain distance its image falls directly on the blind spot. The image of the dot falls on the fovea throughout.
- The change in size of the pupil is the reflex action. Stimulus – Increase in light intensity, effector – circular iris muscles

Let's Practise 10.2

- Refracts light into the eye
 - Enables the eye to see a focused object
 - Allows light to enter the eye
 - Controls the amount of light entering the eye
- The cornea
- Prevents excessive light from entering the eye and damaging the retina; automatic, no learning required; allow sufficient light to enter the eye

Let's Practise 10.3

- Focusing or accommodation
 - Refer to 'Focusing on a distant object' in Section 10.3.

Let's Review

Section A: Multiple-choice Questions

- 1 B 2 C 3 C 4 B

Section B: Structured Questions

- A reflex arc is the shortest pathway by which nerve impulses travel from the receptor to the effector in a reflex action.
 - A: Receptor, B: Sensory neurone, C: Relay neurone, D: Motor neurone, E: Effector
- Person B: Nerve impulses can be transmitted between the brain and the arm muscles (effector). However, nerve impulses generated by the pinprick on the arm skin (receptor) cannot travel to the brain due to the blockage at Y (sensory neurone).
 - Person A: Nerve impulses generated by the pinprick on the arm skin (receptor) can travel to the arm muscles (effector) via the reflex arc to produce a response. However, they cannot be transmitted to the brain to be interpreted as pain due to the blockage at X (relay neurone).
 - Person C: Nerve impulses generated by the pinprick can be transmitted from the arm skin (receptor) to the brain to be interpreted as pain. However, nerve impulses cannot be transmitted to the arm muscles (effector) to move the arm due to the blockage at Z (motor neurone).
- When light falls on an object, rays of light are reflected from the object. Some of these reflected rays fall on the eye. Nerve impulses are produced when light falls on the photoreceptors. These nerve impulses are transmitted via the optic nerve to the brain. The brain interprets these nerve impulses so that we see the object the right way up, front to back, and the right size.
 - Iris
 - Ciliary muscles
 - Choroid
 Refer to Figure 10.20 for labelling.

Section C: Free-response Questions

- The bite stimulates the nerve endings (receptors) in your skin and nerve impulses are produced. Nerve impulses travel along the sensory neurone to the spinal cord. In your spinal cord, the nerve impulses are transmitted across a synapse to a relay neurone which leads to your brain, which interprets the nerve impulses to feel the pain.
- Focusing or accommodation is the adjustment of the lens of the eye so that clear images of objects at different distances are formed on the retina.
 - Focusing takes place in your eyes so that you can see both the printed page (near object) and aeroplane (distant object). Refer to 'Focusing on a distant object' and 'Focusing on a near object' in Section 10.3 for the sequence of events that enables you to see a near object and a distant object.
- Refer to 'What is the pupil reflex?' in Section 10.2.
- Failure to focus (all) light (rays); blurred image. Any reference to the passage of light rays being impaired (e.g. reflection / refraction / deflection / absorption / convergence); possible change in elasticity / ability of accommodate; faded colour vision
- Yes. The ciliary muscles control the thickness of the lens. When the eye sees a distant object, the ciliary muscles relax and the lens becomes thinner and less convex. When the eye sees a near object, the ciliary muscles contract and the lens becomes thicker and more convex. The radial and circular muscles of the iris control the size of the pupil. In bright light, the radial muscles of the iris relax and the circular muscles of the iris contract. The pupil becomes smaller and less light enters the eye. In dim light, the radial muscles of the iris contract and the circular muscles of the iris relax. The pupil becomes bigger and more light enters the eye.

Chapter 11: Infectious Diseases in Humans

Let's Practise 11.1

- Through droplets in the air, direct contact, contaminated food and water
- Both the mask and gloves serve as physical barriers. The mask prevents respiratory droplets from falling into and contaminating the food, while the gloves prevent transmission of pathogens from the hands to the food being prepared.
 - Mask – Through droplets in the air
Gloves – By contaminated food and water

Let's Practise 11.2

- Refer to Table 11.1.
- Student A
 - Viruses have a protein coat and can have DNA for their genetic material. They do not contain materials such as ribosomes. Therefore, the pathogen described is a virus.

Let's Investigate 11.1

- A more effective antibiotic has a bigger transparent area around the disc of antibiotic.
- Two of the antibiotics are ineffective against the bacteria. There is no transparent area around two of the discs. This indicates that the bacteria continued to grow as they were resistant to the antibiotics.

Let's Practise 11.3

- fever, cough
 - Refer to sections on 'Influenza' and 'Pneumococcal Disease' in Section 11.3.
- A vaccine consists of an agent that resembles a pathogen.

Answer Key

- 3 Antibiotics act on bacterial cell walls, break up the bacterial cell membranes and act on ribosomes to inhibit protein synthesis and growth. Viruses do not have cell walls, cell membrane or ribosomes. Therefore, antibiotics are ineffective against them. Viruses reproduce within host cells, unlike bacteria.
- 4 (a) Using antibiotics to treat a viral infection; Not completing the course of prescribed antibiotics
(b) If a full course of antibiotics is not completed, not all the bacteria targeted by the antibiotic will be killed. The bacteria still present in the body can continue to grow and cause another infection. The bacteria could also develop antibiotic resistance.

Let's Review

Section A: Multiple-choice Questions

1 D 2 A 3 A 4 B

Section B: Structured Questions

- 1 (a) Structure A: protein coat; Structure B: DNA or RNA / genetic material (Accept either answer)
(b) A virus has a protein coat, while a bacterium has a cell wall. / A virus can have either DNA or RNA as its genetic material, while a bacterium can only have DNA as its genetic material. / A virus does not have a cell membrane, cytoplasm or ribosomes, but a bacterial cell does. (Any two)
- 2 (a) pathogen (b) infection
(c) white blood cells / lymphocytes (d) antibodies
(e) pathogen (f) pathogen (g) antibodies
- 3 (a) Yes
(b) *Streptococcus pneumoniae* is a type of bacteria which causes an infectious disease known as pneumococcal disease. As pathogens are disease-causing organisms, *Streptococcus pneumoniae* is a pathogen.
- 4 (a) (i) viral infection (ii) antiviral drugs (iii) limit her contact with or maintain safe distancing from non-infected individuals / practise good personal hygiene / clean and disinfect surfaces that she may come in contact with / (Accept other possible answers.)
(b) If a full course of antibiotics is not completed, not all the pathogenic bacteria will be killed. The bacteria still present in the body can continue to grow and cause another infection. They may also undergo mutation and become resistant to the prescribed antibiotics.
- 5 In response to a virus, bacteria produce RNA, while white blood cells in humans produce antibodies. The RNA in the bacteria guides an enzyme to digest and destroy the genetic material of the virus. In the human body, the antibodies produced bind to the virus directly to destroy and kill it.

Section C: Free-response Questions

- 1 Children who are vaccinated are protected against an infectious disease. This reduces the number of children who are infected with the disease, which reduces the chance of an unvaccinated child coming in contact with a child infected with a pathogen. Thus, it gives protection to unvaccinated children against the infectious disease.
- 2 (a) Separators can prevent the spread of droplets of moisture given out from one diner to another. As the COVID-19 virus can spread by droplet infection, the separators prevent the spread of COVID-19 by acting as a physical barrier between the diners at the same table.
(b) Separators should be transparent. / Separators should be waterproof. / Separators should be durable.
(c) Make separators that can be adjusted for height for taller people. / Use long-lasting disinfectant coating for separators.

Chapter 12: Nutrition and Transport in Flowering Plants

Let's Investigate 12.1

- 1 Heat causes the air in the intercellular air spaces in the leaf to expand. Excess air escapes through the stomata as air bubbles. More stomata are found on the lower surface of the leaf than on the upper surface.
2 To provide sufficient heat to expand the air in the air spaces in the leaf.

Let's Practise 12.1

- 1 (a) The cuticle is a waxy layer. It prevents water from adhering to the surface of the leaf and blocking up the stomata.
(b) Air chambers provide buoyancy for the leaves to float in water. This enables the leaves to obtain sufficient sunlight and carbon dioxide for photosynthesis. Air chambers store carbon dioxide produced at night during respiration for photosynthesis in the daytime. Air chambers store oxygen produced during photosynthesis in the daytime to be used for respiration at night.
- 2 Refer to Figure 12.8.

Let's Practise 12.2

- 1 (a) E (b) C (c) E

Let's Investigate 12.2

Observation

- 1 (a) Colourless (b) Green
2 White / pale yellow
3 The iodine turns blue-black, indicating that starch is present.

Discussion

- 1 The alcohol has dissolved and removed the chlorophyll from the leaf.
2 To denature the enzymes and stop chemical reactions in the leaf

Let's Investigate 12.3

- 1 Only the parts exposed to sunlight will be stained blue-black. Sunlight is necessary for photosynthesis.
2 To make sure that starch is absent in the leaves at the beginning of the experiment and any starch detected at the end of the experiment will be due to photosynthesis during the experiment.

Let's Investigate 12.4

Only the green parts of the leaf will be stained blue-black. Only those parts containing chlorophyll will carry out photosynthesis and subsequently form starch, i.e. chlorophyll is necessary for photosynthesis.

Let's Investigate 12.5

The iodine remains brown for the leaf exposed to air without carbon dioxide. The iodine turns blue-black for the leaf in the control set-up. Carbon dioxide is necessary for photosynthesis.

Let's Investigate 12.6

Observation

- 1 Oxygen
2 No gas is given off by the green plant in the control set-up.

Discussion

- 1 The presence of air would cause the experiment to have inaccurate results at the end of the experiment. The gas will not be conclusively oxygen but a mixture of oxygen and the air trapped in the test-tube. It will not be able to show that the gas in the test-tube must be produced during photosynthesis.
- 2 The rate of gas production indicates the rate of photosynthesis.

Let's Investigate 12.7

Conclusion

The rate of photosynthesis increases with increasing light intensity up to a certain point, after which the rate of photosynthesis remains constant.

Discussion

- 1 To ensure that the plant is supplied with sufficient carbon dioxide.
- 2 Allows the plant to adapt to the surrounding conditions like light intensity before the readings are taken.
- 3 Counting bubbles may be an inaccurate way to determine amount of gas produced as the bubbles may be of different sizes. (Note: If a greater amount of plant is used, there will be a greater chance of human error in counting because the rate of bubble production will be faster. Hence, an ideal weight of plant should be used.)

Let's Investigate 12.8

Conclusion

- 1 The rate of photosynthesis increases as temperature increases from 5 °C to 35 °C.
- 2 The temperature at which the rate of bubbling is the highest varies slightly from one type of plant to another. Generally, this temperature is between 40 °C and 45 °C.

Discussion

The rate of photosynthesis decreases. This is due to the denaturation of enzymes, which are made of proteins, and so are affected by high temperatures.

Let's Investigate 12.9

The rate of photosynthesis increases with increasing concentrations of sodium hydrogencarbonate solution up to a certain point, after which the rate of photosynthesis remains constant.

Let's Practise 12.3

1. Put the leaf in boiling water for two minutes to kill the cells and stop enzyme-catalysed reactions in the leaf.
2. Put the boiled leaf in methylated spirit/ethanol/alcohol in a hot water-bath to remove chlorophyll.
3. Gently put the decolourised leaf back into the hot water to soften the leaf and make it more permeable to iodine solution.
- 2 (a) Leaf A received all the conditions essential for photosynthesis. At least one condition essential for photosynthesis was absent for leaf B.
(b) Light / carbon dioxide
(c) Leaf A, because all the conditions essential for photosynthesis were present.
- 3 (a) Graph shape should look like Figure 12.36.
(b) Rate increases with increasing light intensity
(c) Carbon dioxide concentration or temperature of surroundings becomes the limiting factor.
(d) Increase temperature to the optimum — temperature is a limiting factor, increasing temperature increases the rate of enzyme reaction
Increase carbon dioxide concentration — carbon dioxide is a limiting factor at high light intensity, increasing carbon dioxide concentration increases the rate of enzyme reaction

Let's Investigate 12.10

- 1 Xylem
- 2 Water is transported up the plant through the xylem tissue.

Let's Investigate 12.11

- 1 Transport of manufactured food substances from the leaves occurs through the phloem.
- 2 Manufactured food substances (e.g. sugars and amino acids) accumulate above the cut region and cause swelling.

Let's Practise 12.4

- 1 (a) 1, 4 (b) 2, 3
- 2 The diagram would be similar to the diagram shown in the question, only the area above the cut region would be swollen.

Let's Practise 12.5

- 1 The diagram should be similar to the root hair shown in Figure 12.51.
(a) Osmosis
(b) The water potential in the soil must be higher than that in the root hair cell sap. A partially permeable cell membrane must also be present.
- 2 The inorganic fertilisers are soluble and will lower the water potential of the soil solution. Water will move out of the root hair cells by osmosis and the plant cells will plasmolyse.

Let's Investigate 12.12

- 1 Drops of liquid are seen on the inner surface of the bell jar for the set-up with a plant, but not for the control set-up.
- 2 The copper sulfate turns blue, indicating the presence of water. Water vapour given off by the plant condenses on the inner surface of the bell jar.

Let's Investigate 12.13

More water condensed on the inner surface of the bell jar with the leafy twig. This shows that transpiration occurs mainly through the leaves.

Let's Investigate 12.14

The cobalt chloride paper on the lower surface of the leaf turns pink first. This shows transpiration occurs faster through the lower surface. Since leaves have more stomata on the lower surface, we can further conclude that transpiration occurs mainly through the stomata of leaves.

Let's Investigate 12.15

Leaf A. As the lower surface of leaf A that contain more stomata is not covered with a layer of petroleum jelly, more transpiration occurs through the leaf, leading to greater water loss and therefore the most mass is lost.

Let's Investigate 12.18

The potometer measures uptake of water. Not all of the water taken up by the plant is used for transpiration. Some water may be used for photosynthesis and some by the cells to maintain turgidity. Hence, the two rates may be different.

Let's Practise 12.6

- 1 (a) Dry habitat or one in which water is not easily available.

Answer Key

- (b) The leaf has stomata sunken in depressions and long hairs along the lower surface to trap water vapour outside the stomata. This makes the concentration gradient of water vapour between the inside and outside of the leaf less steep and thus reduces the rate of transpiration. The thick cuticle prevents water loss from the leaf surface and thus reduces transpiration.

Let's Review

Section A: Multiple-choice Questions

- 1 D 2 B 3 D 4 A
5 A 6 D 7 B 8 C

Section B: Structured Questions

- (a) Presence of light, presence of chlorophyll, a suitable temperature
(b) Used immediately by cells for respiration or formation of cellulose cell walls; excess glucose is converted to sucrose and transported away, or stored temporarily as starch in the leaf.
- (a) Light intensity, temperature or carbon dioxide concentration
(b) (i) Light intensity
(ii) Carbon dioxide concentration
(c) Amount of chlorophyll
- (a) Carbon dioxide diffuses into the stomata. Water vapour and oxygen diffuse out of the stomata.
(b) Oxygen diffuses into the stomata. Carbon dioxide and water vapour diffuse out of the stomata.
- (a) Stoma will be wider. Guard cells are more curved.
(b) Stoma will be slightly wider. Guard cells are slightly more curved.
- (a) Xylem
(b) Xylem tissue conducts water and dissolved mineral salts from the roots to the stems and leaves. The xylem vessel has an empty lumen without protoplasm or cross-walls, this reduces resistance of water flowing through the xylem. Xylem tissue provides mechanical support for the plant. The walls of xylem vessels are thickened with lignin, which is made of a hard and rigid substance that prevents collapse of the vessel. All the xylem vessels together provide support to the plant organ.

Section C: Free-response Questions

- Refer to Table 12.1.
- Carbon dioxide diffuses from the surrounding air through the stomata into the intercellular air spaces in the leaf. Carbon dioxide then diffuses into the mesophyll cells and is used to form glucose through the process of photosynthesis.
- Refer to Figures 12.51 and 12.52.
- (a) Via active transport, using energy from respiration to absorb salt against the concentration gradient
(b) Seaweeds would not be able to take in essential mineral salts from sea water without the process of active transport. When seaweeds do not obtain these essential mineral salts, they would die of nutrient deficiency. It also lowers the water potential of the cell sap. The cell can still absorb water from the sea water, remain turgid and not die of dehydration.

Chapter 13: Organisms and Their Environment

Let's Practise 13.1

- Trophic level two (aphid) and trophic level five (snake)
- A food web shows that animals may feed on more than one kind of organism.
- Respiration; uneaten body parts; faeces; excretory products; dead bodies (Any three).

Let's Practise 13.2

- The pyramid of biomass considers the size and mass of organisms.

Let's Practise 13.3

- (a) A: Decomposer, C: Animal, D: Atmosphere
(b) 1: Respiration, 2: Photosynthesis, 3: Respiration, 4: Feeding
(c) Processes 2 and 4 (d) Process 2

Let's Practise 13.4

- A carbon sink is an area that stores carbon from the atmosphere for a long period of time. It stores more carbon than it releases.
- Carbon sinks act as a carbon reservoir. They remove carbon dioxide from the atmosphere and this helps to reduce the rate of global warming. We can increase the number of carbon sinks via reforestation.

Let's Practise 13.5

- Refer to 'Insecticides' in Section 13.5.
- Refer to 'Effects of Non-biodegradable Plastic Waste on the Ecosystem' in Section 13.5.
- Refer to 'Sewage' in Section 13.5.

Let's Practise 13.6

- The effects of many organisms on the ecosystem are yet unknown. Loss of species could greatly upset the ecological balance. Biodiversity is also a valuable natural resource. Many organisms that have not yet been studied may be potentially of great economic importance, for example, by providing raw materials for industries, cures for diseases, new sources of food.
- It will limit humanity's use of natural resources such as land, forests and animals. This aids conservation of these resources.

Let's Review

Section A: Multiple-choice Questions

- 1 D 2 D 3 B 4 A 5 A 6 A

Section B: Structured Questions

- (a) Photosynthesis
(b) Producers contain chlorophyll that absorbs light to convert carbon dioxide and water into glucose, which is a chemical store of energy, whereas consumers obtain their energy by feeding on other organisms.
- (a) The pyramids of biomass and numbers have a broad base and narrow towards the top.
(b) The pyramid of biomass has a broad base and narrows towards the top. The pyramid of numbers has a narrow base with a bulge in the middle and narrows towards the top.
- (a) Sparrows, ladybirds, hawks and humans
(b) It can manufacture its own food by photosynthesis.
(c) The pyramid of numbers has a broad base, narrows towards the middle and ends with a broad top.
- Advise him or her not to overuse the insecticide and to avoid watering too frequently. Even though the pollution is low and the insecticide is biodegradable, the rain may wash the insecticide into the water body nearby and poison the fish in the water body.
- (a) phytoplankton → zooplankton → minnows → needlefish → ospreys
(b) 1333.3 (to 1 decimal place) → 12.5 → 4 → 10
From phytoplankton to zooplankton
(c) The eggs with thin eggshell are much more likely to break, preventing the development and hatching of healthy chicks. Eggs with thin shells may also be easily broken by predators. Osprey population would decrease because of reduced

reproduction rate. Ospreys are top consumers, so with a reduced population of ospreys, the population of needlefish may increase, causing corresponding decreases in the population of minnows, which are food for the needlefish.

- (d) Concentration of chemicals in the environment does not give a true picture as increase in concentration of chemicals occurs along food chains. Also, different organisms respond differently to the same concentration of the chemicals.

Section C: Free-response Questions

- During *photosynthesis*, green plants absorb carbon dioxide from the atmosphere and use it to manufacture food substances like glucose. When animals feed on green plants, the carbon compounds become part of the bodies of these animals. The carbon compounds may also be preserved in fossil fuels. When fossil fuels undergo *combustion*, carbon dioxide is released into the atmosphere. Living organisms release carbon dioxide into the environment during *respiration*. *Decomposition* of the bodies of dead organisms also permits carbon dioxide to be released back into the environment.
- X: producer, Y: primary consumer.
The rise and fall in the population of Y follow that of X. The average population size of Y is smaller than that of X.
- (a) A carbon sink is an area that stores carbon from the atmosphere for a long period of time. It stores more carbon than it releases. Forests and oceans are examples of carbon sinks.
(b) Carbon sinks remove carbon dioxide from the atmosphere and this helps to reduce the rate of global warming.
- Refer to 'What are the undesirable effects of deforestation?' in Section 13.5.
- Refer to 'Sewage' in Section 13.5.
- Refer to Figure 13.35.

Chapter 14: Molecular Genetics

Let's Practise 14.1

- A chromosome is made up of a DNA molecule and proteins. The DNA carries genes that are responsible for certain characteristics in the organism.
- DNA consists of two strands that are twisted around each other in the form of a double spiral.
- 10%

Let's Practise 14.2

1 C 2 B

Let's Practise 14.3

- A transgenic organism is an organism that has a foreign gene inserted into its DNA.
- It is easier and cheaper to produce in large quantities. There is less risk of contamination by microorganisms.

Let's Practise 14.4

- Refer to 'What Are Some Ethical Considerations of Genetic Engineering?' in Section 14.4.

Let's Review

Section A: Multiple-choice Questions

1 A 2 A 3 C 4 A

Section B: Structured Questions

- (a) Yes. By applying the rule of base pairing. (b) 18.2%
- (a) Restriction enzyme (b) DNA ligase (c) Insulin

Section C: Free-response Questions

- DNA consists of two strands. Each DNA strand is made up of nucleotides. Each nucleotide consists of a sugar, a phosphate group and a nitrogenous base. The base may be an adenine (A), guanine (G), thymine (T) or cytosine (C). The bases of one strand are joined to the bases of the opposite strand by hydrogen bonds. The base A is bonded to T while C is bonded to G. The two strands of DNA are twisted into a double helix. DNA molecule consists of many genes along its length. A chromosome is a tightly coiled DNA molecule. A chromosome hence consists of many genes along its length.
- Genes store information as a sequence of nucleotides, which codes for the sequence of amino acids that make up a particular polypeptide.
- (a) Refer to Figure 14.13.
(b) It does not induce allergic response in the patient as insulin produced is identical to human insulin. It is easier and cheaper to produce insulin in large quantities. There is less risk of contamination by disease-causing microorganisms like bacteria.
- Refer to 'What Are Some Ethical Considerations of Genetic Engineering?' in Section 14.4.

Chapter 15: Modes of Reproduction

Let's Practise 15.1

- Asexual reproduction is the process that results in the production of genetically identical offspring from one parent, without the fusion of gametes.
- Mitosis is a type of cell division giving rise to genetically identical cells in which the chromosome number is maintained.

Let's Practise 15.2

- (a) Sexual reproduction is a process involving the fusion of two gametes to form a zygote. It produces genetically dissimilar offspring.
(b) Meiosis is a type of cell division that gives rise to genetically dissimilar cells in which the chromosome number is halved due to the separation of homologous chromosomes.
- Homologous chromosomes are chromosome pairs that have the same shape, same genes and same sequence of genes.
- Meiosis produces haploid gametes that are genetically dissimilar.
- 10

Let's Review

Section A: Multiple-choice Questions

1 D 2 C 3 B

Section B: Structured Questions

- (a) Asexual and sexual reproduction
(b) Refer to Tables 15.1 and 15.2.
- (a) Mitosis produces genetically identical daughter cells but meiosis produces genetically different daughter cells.
(b) Haploid number of chromosomes contains a single set of chromosomes whereas diploid number of chromosomes contains two sets of chromosomes.

Section C: Free-response Questions

- Mitosis is important for the growth of a multicellular organism.
• Mitosis is important for repair of worn-out parts of the body of an organism.
• In some organisms, mitosis is important for asexual reproduction.

Answer Key

- 2 Meiosis is a reduction division in cells.
- It produces gametes that contain half the number of chromosomes (haploid number) as that of the normal body cell (diploid number).
 - During sexual reproduction, when two gametes fuse, the normal diploid number of chromosomes is restored in the zygote. This maintains the diploid chromosome number in the species.

Chapter 16: Reproduction in Plants

Let's Practise 16.1

- 1 (a) Enclose and protect the other parts of the flower in the bud stage
(b) Brightly coloured to attract insects for pollination, provides a platform for insects to land, have lines that guide insects to the base of the petal in some plants
(c) Produces and releases pollen grains
(d) Receives pollen grains and stimulates them to germinate

Let's Practise 16.2

- 1 • It is bisexual.
• The anthers are close to the stigma.
• Anthers and stigma mature at the same time.
- 2 (a) Refer to Table 16.2.
(b) These include having only male or female flowers on individual plant, anthers and stigmas (if on the same plant) maturing at different times, and anthers and stigmas (if on the same plant) located far apart.
- 3 (a) Refer to 'Pollination of Clitoria' in Section 16.2.
(b) Refer to 'How Are Insect-pollinated and Wind-pollinated Flowers Different?' in Section 16.2.

Let's Practise 16.3

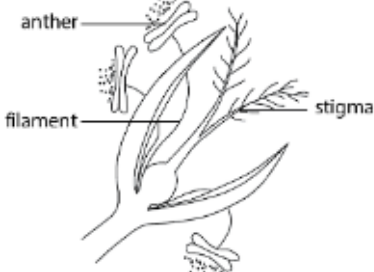
- 1 A pollen grain will germinate when it comes into contact with the sugary fluid secreted by a mature stigma.
- 2 The male gamete travels through the pollen tube which leads to the ovule.
- 3 (a) The ovary develops into a fruit.
(b) The ovule develops into a seed.

Let's Review

Section A: Multiple-choice Questions

- 1 C 2 C 3 A 4 B 5 C

Section B: Structured Question

- 1 (a)
- 
- anther —————
- filament —————
- stigma

- (b) By wind
- (c) Stigma: large and feathery in order to provide a large surface area to trap pollen
Anther: large and produces an abundance of pollen to offset wastage
Filament: long and protruding to expose anther to wind; slender and pendulous in order to sway readily in wind to dislodge pollen from the anther

Section C: Free-response Questions

- 1 Pollination is the transfer of pollen grains from the anther to the stigma, while fertilisation is the process by which the nucleus of the male gamete fuses with the nucleus of the female gamete to form a zygote.
- 2 Self-pollination is the transfer of pollen grains from the anther to the stigma of the same flower or of a different flower on the same plant. Cross-pollination is the transfer of pollen grains from the anther of a flower on one plant to the stigma of a flower on another plant of the same species.

Chapter 17: Reproduction in Humans

Let's Practise 17.1

- 1 Sperm requires a temperature slightly lower than that of the body to develop properly.
- 2 (a) A: Uterus, B: Oviduct, C: Ovary, D: Cervix, E: Vagina
(b) (i) E (ii) B (iii) A (iv) C (v) C
- 3 Refer to Table 17.1 in Section 17.1.

Let's Practise 17.2

- 1 (a) Oestrogen causes the repair and growth of the uterine lining. Progesterone maintains the uterine lining by causing it to thicken further and be supplied with blood capillaries.
(b) 10th–15th day of the menstrual cycle
(c) Part of the uterine lining breaks down and is shed together with some blood in the menstrual flow.

Let's Practise 17.3

- 1 A zygote is a fertilised egg.
- 2 (a) The umbilical cord contains blood vessels through which deoxygenated blood and metabolic waste products are transported from the fetus to the placenta, and oxygenated blood and food substances are transported from the placenta to the fetus.
(b) The placenta allows the diffusion of substances from fetal to maternal blood and vice versa, and produces the hormones oestrogen and progesterone for the repair, growth and maintenance of the uterine lining.
(c) The amniotic sac encloses the embryo inside the womb in a fluid-filled cavity.
(d) The amniotic fluid provides support and protection for the fetus and lubrication of the birth canal during childbirth.

Let's Practise 17.4

- 1 Human Immunodeficiency Virus (HIV)
- 2 HIV can be transmitted through sexual intercourse / sharing of hypodermic needles / blood transfusion / pregnancy when an infected person is involved. (Any two)

Let's Review

Section A: Multiple-choice Questions

- 1 C 2 C 3 C 4 D 5 A

Section B: Structured Questions

- 1 (a) A: Sperm duct, B: Prostate gland, C: Urethra, D: Testis, E: Ureter, F: Urinary bladder
(b) (i) C (ii) A (iii) D
(c) Testis → sperm duct → urethra → outside the body

- 2 (a) Menstruation occurs. The uterine lining and unfertilised egg break down and are shed from the body via the vagina together with some blood.
 (b) Five days
 (c) The uterine lining is repaired. It grows and thickens.
 (d) The uterine lining thickens further and becomes richly supplied with blood capillaries.
 (e) X should be placed at point B.
- 3 (a) A: amniotic cavity / amniotic fluid, B: placenta, C: amnion / amniotic sac, D: urinary bladder, E: vagina
 (b) Any of the following for each:
 A: Supports and cushions the fetus before birth; absorbs shock and protects the fetus against pressure from sudden movements of its mother's body; protects the fetus against physical injury; lubricates and reduces friction in the vagina or birth canal during birth; allows fetus to move freely during growth
 B: Allows oxygen and dissolved food substances like glucose to diffuse from the mother's blood into the fetus's blood; allows excretory products like urea to diffuse from the fetus's blood into the mother's blood; allows protective antibodies to diffuse from the mother's blood into the fetus's blood so that the fetus is protected against certain diseases; produces progesterone which maintain uterine lining in a healthy state during pregnancy
 (c) (i) P: umbilical artery, Q: umbilical vein
 Any of the following reasons: P has a thicker wall than Q; P has a smaller lumen than Q. The umbilical cord contains two umbilical arteries and one umbilical vein.
 (ii) P transports metabolic waste products such as urea and carbon dioxide from the fetus to the placenta.
 Q transports oxygen and nutrients like glucose and amino acids from the placenta to the fetus.

Section C: Free-response Questions

- 1 Refer to 'What Are the Stages in the Menstrual Cycle?' in Section 17.2.
 2 (a) Diseases transmitted through sexual intercourse
 (b) Refer to 'How can we prevent and control HIV transmission?' in Section 17.4.

Chapter 18: Inheritance

Let's Practise 18.1

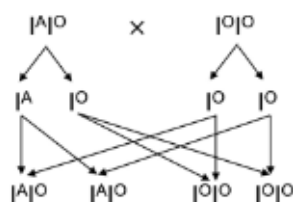
- 1 The student used only 50 samples of pea plants. Statistically, ratios are often inaccurate when sample number is small.

Let's Practise 18.2

50%

Let's Practise 18.3

- 1 The child that receives I^O alleles from both parents will have blood group O.



Let's Investigate 18.1

- (a) T and t: 40; t and t: 20
 (b) Expected are theoretical or statistical / spinning is random or due to chance; disc poorly made / toothpick does not pass through middle; error in counting
 (c) Fertilisation is a random process.
 (d) Alleles in the gametes

Let's Practise 18.4

- 1 True
 2 (a) A and B are sex chromosomes (X chromosomes).
 (b) Female
 3 22

Let's Investigate 18.2

- 1 Height: There are many intermediate heights.
 2 Type of eyelids: There are two clearly defined forms, with no intermediate forms.

Let's Practise 18.5

- 1 (a) Variation refers to the differences in traits between individuals of the same species.
 (b) Sex / ABO blood groups / height / eyelid type / earlobe attachment, etc. (Any two)
 2 (a) Mutation is a change in the sequence of a gene or in the chromosome number.
 (b) Gene mutation: sickle cell anaemia, albinism
 Chromosomal mutation: Down syndrome

Let's Practise 18.6

- 1 Natural selection refers to a process where organisms with desirable alleles and traits are 'selected or favoured' to survive and pass on their alleles to their offspring.
 2 Variation and competition

Let's Review

Section A: Multiple-choice Questions

1 B 2 A 3 B 4 D 5 D 6 C 7 A 8 C

Section B: Structured Questions

- 1 (a) Test cross the normal coat rabbit with c^2c^2 rabbits.
 (b) If the normal rabbit has genotype:
 – CC, then all the offspring will have normal coat;
 – Cc^2 , then the ratio of offspring produced will be 1 normal : 1 Himalayan;
 – Cc^2 , then the ratio of offspring produced will be 1 normal : 1 albino.
 2 (a) 50% (b) 25% (c) 100% (d) 0

Section C: Free-response Question

- 1 Mutations cause organisms to show variation, i.e. differences in characteristics, and result in varieties. Competition among the different varieties results in the survival of the fittest. Through a process of natural selection, those organisms that are best fitted to the environment survive and reproduce. They pass down their favourable genes and characteristics to their offspring. Over time, more beneficial qualities (genes or alleles) may accumulate in a species. The new breed of organisms may be better adapted to their new environment. They may even change so much that they become a new species which differs from the original stock from which they have evolved. When this happens, evolution has occurred.

Quick Revision Guide

Chapter 1: Cell Structure and Organisation

- A **cell** is a unit of life. It consists of a mass of living matter called protoplasm.
- A **partially permeable membrane** allows only some substances to pass through it.
- Differences between plant and animal cells:
 - Plant cells have a cell wall but not animal cells.
 - Plant cells have chloroplasts but not animal cells.
 - Plant cells have a large central vacuole, but animal cells have many small vacuoles.
- Cells become specialised for a specific function. Examples of specialised cells include:
 - Muscle cell: has many mitochondria to supply more energy
 - Red blood cell: lacks a nucleus to store more haemoglobin for the transport of oxygen, has a circular and biconcave shape to increase the surface area-to-volume ratio so that oxygen can diffuse in and out at a higher rate
 - Root hair cell: has a long and narrow root hair to increase the surface area-to-volume ratio to absorb water and mineral salts at a higher rate

Chapter 2: Movement of Substances

- **Concentration gradient** is the difference in concentration between two regions.
- **Diffusion** is the net movement of particles (atoms, molecules or ions) from a region where they are of higher concentration to a region where they are of lower concentration, that is, down a concentration gradient.
- **Surface area-to-volume ratio** determines the rate at which nutrients and waste materials move across the cell membrane.
- **Water potential** is a measure of the tendency of water to move from one place to another.
- A dilute solution has a higher **water potential** than a concentrated solution. Water always moves from a region of higher water potential to a region of lower water potential across a partially permeable membrane.
- **Osmosis** is the net movement of water molecules from a region of higher water potential to a region of lower water potential, through a partially permeable membrane.
- **Active transport** is the process in which energy is used to move the particles of a substance across a membrane against its concentration gradient, that is, from a region where the particles are of lower concentration to a region where they are of higher concentration.

Chapter 3: Biological Molecules

- **Carbohydrates** are organic molecules made up of the elements carbon, hydrogen and oxygen. The hydrogen and oxygen atoms are present in the ratio 2:1. Carbohydrates may be classified as **single sugars**, **double sugars** or **complex carbohydrates**.
- The presence of reducing sugars can be detected by the **Benedict's test**. The solution turns green, yellow, orange or red, depending on the amount of reducing sugar present. A red precipitate may also be formed.

- The presence of starch can be detected by the **iodine test**. Iodine solution turns from brown to blue-black in the presence of starch.
- **Fats** are organic molecules made up of the elements carbon, hydrogen and oxygen. Unlike carbohydrates, fats contain much less oxygen in proportion to hydrogen.
- The presence of fats can be detected by the **ethanol emulsion test**. A white emulsion is formed when ethanol and water are added to fats.
- **Proteins** are organic molecules made up of the elements carbon, hydrogen, oxygen and nitrogen. Another element, sulfur, may also be present. **Amino acids** are compounds that make up a protein molecule.
- The presence of proteins can be detected by the **biuret test**. The blue biuret solution turns violet when proteins are present.

Chapter 4: Enzymes

- A **catalyst** is a substance that can alter or speed up a chemical reaction, without itself being chemically changed at the end of the reaction.
- **Enzymes** are proteins that function as biological catalysts. They catalyse or speed up the rate of chemical reactions. They remain chemically unchanged at the end of the reaction.
- The energy needed to start a chemical reaction is called **activation energy**.
- The substances on which enzymes act are called **substrates**.
- Enzyme reactions depend on the presence of **active sites**, which are grooves on the surface of an enzyme molecule into which only the substrate molecule(s) with a complementary shape can fit.
- An **enzyme-substrate complex** is formed when a substrate with a complementary shape fits into the active site of an enzyme.
- **Denaturation** is the change in the three-dimensional structure of an enzyme or any other soluble protein, caused by heat or chemicals such as acids or alkalis. Enzyme denaturation takes place when there are extreme changes in pH and at temperatures above the optimum.

Chapter 5: Nutrition in Humans

- **Nutrition** is the process by which organisms obtain food and energy for growth, repair and maintenance of the body.
- **Feeding** or **ingestion** is the taking in of food into the body.
- **Digestion** is the process whereby large food molecules are broken down into smaller, soluble molecules that can be absorbed into the body cells.
- **Absorption** is the process whereby digested food substances are absorbed into the bloodstream.
- **Assimilation** is the process whereby some of the absorbed nutrients are converted into new cytoplasm or used to provide energy.
- **Egestion** is the process whereby undigested matter is removed by the body.

- **Peristalsis** is the rhythmic, wave-like muscular contractions in the wall of the alimentary canal.
- **Physical digestion** involves the mechanical breakdown of food into small particles.
- **Chemical digestion** is the breaking down of the large molecules in food into small soluble molecules that can be absorbed.
- The **hepatic portal vein** transports blood rich in absorbed nutrients from the small intestine to the liver.
- **Deamination** is the process by which amino groups are removed from amino acids and converted to urea.

Chapter 6: Transport in Humans

- The **circulatory system** is the main **transport system** in humans. It consists of the **heart**, **blood** and **blood vessels**. The main components of blood are plasma, red blood cells, white blood cells and platelets.
- **Arteries** are the blood vessels that carry blood away from the heart. **Veins** are the blood vessels that carry blood back to the heart.
- The **aorta** branches to form smaller **arteries**, which in turn branch into tiny vessels called **arterioles**. The arterioles divide and their branches become very tiny blood vessels called **capillaries**.
- Capillaries join to form small **venules** as they leave the organ or tissue. Venules join to form bigger **veins**. **Valves** are found in veins to prevent backflow.
- The **cardiac cycle** refers to the sequence of events that takes place in one heartbeat.
- **Blood pressure** is the force that blood exerts on the walls of blood vessels.

Chapter 7: Respiration in Humans

- **Aerobic respiration** is the release of energy by the breakdown of glucose in the presence of oxygen. Carbon dioxide and water are released as waste products. Aerobic respiration releases a large amount of energy.
glucose + oxygen $\rightarrow$ carbon dioxide + water
 $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$
- **Anaerobic respiration** is the release of energy by the breakdown of glucose in the absence of oxygen. Anaerobic respiration releases a relatively small amount of energy.
- **Lactic acid** is a by-product of anaerobic respiration in human muscle cells.
glucose $\rightarrow$ lactic acid
- **Oxygen debt** is the amount of oxygen required to remove lactic acid. The muscles are said to incur an oxygen debt if there is insufficient oxygen to meet the demands of the vigorous muscular contractions.
- **Gas exchange** is the exchange of gases between an organism and the environment.
- The **alveolus** is the site of gas exchange in humans.
- **Inspiration** or **inhalation** is the taking in of air.
- **Expiration** or **exhalation** is the giving out of air.

Chapter 8: Excretion in Humans

- **Metabolic activities** are chemical activities that occur within our body cells.
- **Metabolic waste products** or **excretory products** are substances produced during metabolic activities that are harmful or toxic to our bodies.
- **Deamination** is the removal of the nitrogen-containing part of amino acids to form urea.
- **Excretion** is the removal of metabolic waste products, toxic substances and substances in excess of the body's requirements.
- The human urinary system consists of a pair of **kidneys**, a pair of **ureters**, a **urinary bladder** and the **urethra**.
- The **kidneys** excrete urea and excess salt and water as urine.
- The **ureter** is a narrow tube that connects the kidney to the urinary bladder. Urine from each kidney passes through the ureter to the urinary bladder.
- The **urinary bladder** is an elastic muscular bag located in front of the rectum. It stores urine.
- The **urethra** is the duct through which urine passes from the bladder to outside of the body.
- **Nephrons** are the basic functional units of the kidney. They are tiny kidney tubules where urine is formed.
- **Ultrafiltration**, the first stage in urine formation, is the process by which small molecules are filtered out of the blood by the glomerulus into the Bowman's capsule.
- **Selective reabsorption**, the second stage in urine formation, is the process by which useful substances in the filtrate are reabsorbed back into the blood capillaries as the filtrate passes along the nephron.
- **Osmoregulation** is the control of water and solute concentrations in the blood to maintain a constant water potential in the body.
- **Antidiuretic hormone (ADH)**, which is produced by the hypothalamus and released by the pituitary gland. It controls the amount of water in the blood plasma and increases water reabsorption at the nephrons.
- A **dialysis machine** mimics the functions of a kidney. It helps to clean the patient's blood from metabolic waste products and toxins.

Chapter 9: Homeostasis and Hormonal Control

- **Homeostasis** is the maintenance of a constant internal environment.
- In homeostatic control, the body reacts to bring about an opposite effect to the changes detected. This is called **negative feedback**.
- A **hormone** is a chemical substance produced in minute quantities by an endocrine gland. It is transported in the bloodstream to target organ(s) where it exerts its effect(s).
- Endocrine glands are ductless gland that secrete hormones directly into the bloodstream. The bloodstream then distributes the hormone around the body.

Quick Revision Guide

- The pancreas contains special groups of cells known as the **islets of Langerhans** that secrete the hormones **insulin** and **glucagon** into the bloodstream. **Insulin** promotes the utilisation of glucose by the cells and stimulates the conversion of glucose into glycogen. **Glucagon** increases blood glucose concentration by stimulating the conversion of glycogen into glucose, and the conversion of fats and amino acids into glucose.
- **Diabetes mellitus** or diabetes is a disease in which the body is unable to control its blood glucose concentration in order for it to remain within normal limits. **Type 2 diabetes**, or late-onset diabetes, develops due to **insulin resistance**. This occurs when the target cells do not respond well to insulin and are unable to take in excess glucose in the blood, resulting in the blood glucose level remaining high.
- **Vasodilation** is the dilation of the arterioles. **Vasoconstriction** is the constriction of the arterioles.
- **Sensory receptors**, found in sense organs, are the structures in the body that detect changes in the environment. Those that detect changes in temperature are called **thermoreceptors**.

Chapter 10: The Nervous System and the Eye

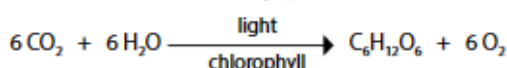
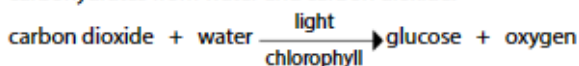
- A **stimulus** is any change in the environment that causes an organism to react. An organism's reaction to a stimulus is called a **response**. The ability to respond to a stimulus is termed **sensitivity** or irritability.
- The human **nervous system** is made up of the **central nervous system (CNS)**, consisting of the brain and the spinal cord; and the **peripheral nervous system (PNS)**, consisting of the cranial nerves, the spinal nerves and the sense organs.
- The **sense organs** receive stimuli through the sense receptors found in them.
- **Nerve impulses** are electrical signals or messages produced by receptors. They are carried or transmitted by **nerves**. Nerves transmit impulses from the receptors to the central nervous system, and from there to the **effectors**.
- A **sensory neurone** transmits nerve impulses from the sense organs or receptors to the central nervous system.
- A **relay neurone** transmits nerve impulses from the sensory neurone to the motor neurone.
- A **motor neurone** transmits nerve impulses from the central nervous system to the effectors.
- A **nerve fibre** is a strand of cytoplasm extending from the cell body. It transmits nerve impulses along its length.
- A **synapse** is a junction between two neurones.
- A **voluntary action** is a deliberate action, which means that it happens under conscious control.
- A **reflex action** is an immediate response to a specific stimulus without conscious control.
- An **involuntary action** is automatic, not under conscious control, such as a reflex action.
- A **reflex arc** is the shortest pathway by which nerve impulses travel from the receptor to the effector in a reflex action.
- The **pupil reflex** is a reflex action where the pupil changes in size in response to changes in light intensity.
- **Focusing** or **accommodation** is the adjustment of the lens of the eye so that clear images of objects at different distances are formed on the retina.

Chapter 11: Infectious Diseases in Humans

- A **disease** is a condition that causes the body to function less effectively. Diseases produce specific signs or symptoms.
- **Infectious** or **transmissible diseases** can be spread from one person to another. They are caused by disease-causing organisms called **pathogens**.
- A typical **bacterial cell** has a cell wall, DNA and organelles such as ribosomes, but does not have a nucleus. Some bacteria are pathogenic (disease-causing) and some are non-pathogenic (non disease-causing).
- A typical **virus** has a protein coat enclosing its genetic material, which is either DNA or RNA. A virus is not considered a cell because it does not have a cell membrane, cytoplasm or organelles.
- **Influenza**, or flu, is a disease that attacks the respiratory system and is caused by the influenza virus. It is transmitted mainly by droplet infection and by contact with contaminated objects and surfaces.
- **Pneumococcal disease** is caused by pneumococcus bacteria. Some signs and symptoms of pneumococcal disease include: fever, headache, vomiting, cough, chest pain and rapid breathing.
- A **vaccine** is a substance that is introduced into the body to protect it against a disease. A vaccine contains an agent that resembles a pathogen or a weakened form of the pathogen. The process of receiving a vaccine is known as **vaccination**.
- Vaccines stimulate white blood cells to produce **antibodies**. These antibodies work quickly to defend the body against pathogens.
- **Antibiotics** are drugs used to treat bacterial infections. Antibiotics are ineffective against viruses.

Chapter 12: Nutrition and Transport in Flowering Plants

- **Chlorophyll** is a green pigment in the chloroplasts of plants, which absorbs sunlight.
- **Stomata** are the minute openings present in the epidermal layers of the leaf.
- **Transport** or **vascular tissues** are vessels that run up and down the plants carrying materials. There are two types of transport tissues in plants: the **xylem** and the **phloem**.
- Xylem tissue consists mainly of **xylem vessels**. The functions of xylem tissue include conducting water and dissolved mineral salts from the roots to the stems and leaves and providing mechanical support for the plant.
- Phloem consists mainly of **sieve tubes** and **companion cells**. Each sieve tube consists of a column of elongated, thin-walled living cells called **sieve tube cells** or **sieve tube elements**. The 'cross-walls' separating the cells are called **sieve plates**.
- **Photosynthesis** is the process by which plants synthesise carbohydrates from water and carbon dioxide.



- A **limiting factor** is any factor that directly affects the rate of a chemical reaction. The rate of the reaction can only be increased if the value of the limiting factor is increased. Light intensity, carbon dioxide concentration and temperature are possible limiting factors of photosynthesis.
- **Translocation** is the transport of manufactured food substances such as sugars and amino acids in plants.
- **Transpiration** is the loss of water vapour from the aerial parts of a plant, mainly through the stomata of the leaves.
- The **rate of transpiration** is affected by wind or air movement, temperature, light and humidity of the surroundings.

Chapter 13: Organisms and Their Environment

- A **producer** is an organism that makes its own food substances.
- **Consumers** are organisms that are not able to make their own food. They obtain energy and nutrients by feeding on other organisms.
- **Decomposers** are organisms that get their energy by breaking down dead organisms, faeces and excretory products.
- A **food chain** is a series of organisms, beginning with the producer, through which energy and nutrients are transferred.
- A **trophic level** is the position of an organism in a food chain.
- A **food web** consists of a network of interconnected food chains.
- In an ecosystem, energy does not flow in a cycle. The energy flow is **non-cyclical**.
- An animal that feeds on another animal is called a **predator**. An animal that is eaten by another animal is called a **prey**.
- **Ecological pyramids** are horizontal bar diagrams used to show food and energy relationships among organisms.
- A **pyramid of numbers** allows us to compare the number of organisms present in each trophic level at a particular time.
- A **pyramid of biomass** allows us to compare the mass of organisms present in each trophic level at a particular time.
- The **carbon cycle** is made up of the various processes by which carbon, in the form of carbon dioxide, is removed from and released into the environment.
- A **carbon sink** is an area that stores carbon compounds from the atmosphere for a long period of time. It stores more carbon than it releases.
- Natural resources are resources supplied by nature.
- **Renewable natural resources**, such as air, water, soil, forests and wildlife, can be replaced in the ecosystem by natural cycles as long as they are not overused.
- **Non-renewable natural resources**, such as fossil fuels, take millions of years to form naturally and cannot be replaced quickly enough.
- **Deforestation** is the clearing of forests.
- **Global warming** is the rise in global temperature, mainly caused by increasing concentrations of greenhouse gases in the atmosphere.
- **Climate change** refers to the changes in weather patterns over a long period of time.

- **Pollution** is the process by which harmful substances are added to the environment, making it undesirable or unfit for life.
- **Sewage** is water-carried waste matter from homes or industries.
- **Eutrophication** is the process by which water receives excess nutrients such as phosphates and nitrates, causing excessive growth of algae and water plants.
- **Bioaccumulation** occurs when certain chemicals, e.g., insecticides, are not excreted, but are accumulated in the bodies of organisms.
- **Biomagnification** occurs when toxins or insecticides are passed from one trophic level to the next with increasing concentration along the food chain.
- **Biodiversity** refers to the range of species that are present in a particular ecosystem.
- **Conservation** is the protection and preservation of natural resources in the environment.

Chapter 14: Molecular Genetics

- **Deoxyribonucleic acid** or **DNA** is a molecule that carries genetic information that is important for all cellular functions, such as **cell division** and **cell differentiation**.
- A **chromosome** consists of a DNA molecule coiled around proteins.
- The basic unit of DNA is called a **nucleotide**. Each nucleotide is made up of a **sugar**, a **phosphate group** and a **nitrogenous base**.
- Four nitrogenous **bases** are **adenine** (A), **cytosine** (C), **guanine** (G) and **thymine** (T).
- Nucleotides can be joined together to form long chains called **polynucleotides**.
- According to the **rule of base pairing**, adenine (A) is bonded to thymine (T) and cytosine (c) to guanine (G).
- A **gene** is a sequence of DNA nucleotides that controls the formation of a single polypeptide. It is also a unit of inheritance.
- The **genetic code** is the message stored by a gene that determines how a protein should be made in a cell.
- **Genetic engineering** is a technique used to transfer genes from one organism to another. Individual genes may be cut off from the cells of one organism and inserted into the cells of another organism of the same or different species. The transferred gene can express itself in the recipient organism.
- A **vector** is required for the transfer of genes. A vector can be another DNA molecule, a bacterium or a virus that is used to carry the genes of one organism into another.
- A plasmid is an example of a vector. **Plasmids** are small circular DNA, obtained from bacteria. They can be used to transfer genes.
- A **transgenic organism** is an organism that has a foreign gene inserted into its genome or DNA.
- **Restriction enzymes** can recognise the **restriction sites** and cut the DNA at these parts to produce **sticky ends**.

Chapter 15: Modes of Reproduction

- **Asexual reproduction** is the process that results in the production of genetically identical offspring from one parent, without the fusion of gametes.
- **Mitosis** is a type of cell division giving rise to genetically identical cells in which the chromosome number is maintained. Mitosis is important in asexual reproduction, for growth in multicellular organisms and in the repair of damaged tissues.
- **Sexual reproduction** is a process involving the fusion of the nuclei of the male and female gametes to form a **zygote**. It produces genetically dissimilar offspring.
- **Meiosis** is a type of cell division that gives rise to genetically dissimilar cells in which the chromosome number is halved due to the separation of homologous chromosomes.
- A **haploid** cell is a cell with one set of chromosomes.
- A **diploid** cell is a cell with two sets of chromosomes, one set from the male parent and the other from the female parent.
- **Homologous chromosomes** are chromosome pairs that have the same shape, same genes and same sequence of genes.

Chapter 16: Reproduction in Plants

- A complete flower consists of the **flower stalk**, **receptacle**, **sepals**, **petals**, **stamens** and **carpels (pistils)**.
- The **stamen** is the male part of the flower. It consists of an **anther** and a **filament**.
- The **carpel** or **pistil** is the female part of the flower. It consists of an **ovary**, a **style** and one **stigma**.
- **Pollination** is the transfer of pollen grains from the anther to the stigma.
- **Self-pollination** is the transfer of pollen grains from the anther to the stigma of the same flower or of a different flower on the same plant.
- **Cross-pollination** is the transfer of pollen grains from one plant to the stigma of a flower in another plant of the same species.
- **Fertilisation** is the process by which the nucleus of the male gamete fuses with the nucleus of the female gamete to produce a zygote.

Chapter 17: Reproduction in Humans

- Parts of the male reproductive system include: **testis**, **scrotum**, **sperm duct**, **prostate gland**, **urethra** and **penis**.
- Parts of the female reproductive system include: **ovary**, **oviduct**, **uterus**, **cervix** and **vagina**.
- The **sperm** is the male gamete. The **ovum** (plural: **ova**) or **egg** is the female gamete.
- **Menstruation** is the monthly discharge of blood or menses from the uterus via the vagina.
- Menstruation is part of the **menstrual cycle**, which takes place in the female reproductive organs every month.
- **Ovulation** is the release of the egg from the ovary.
- Copulation or sexual intercourse is the process when a male's penis becomes stiff and erect, allowing it to enter the vagina of a female.

- **Fertilisation** is the process by which the nucleus of the male gamete fuses with the nucleus of the female gamete to produce a zygote.
- The zygote divides by mitosis to form a ball of cells called the **embryo**.
- **Implantation** occurs when an embryo becomes embedded in the uterine lining.
- The **placenta** is made up of the villi and the uterine lining, in which the villi are embedded.
- The **umbilical cord** is the tube that attaches the embryo to the placenta.
- A **sexually transmitted infection (STI)** is a disease spread or transmitted through sexual intercourse.
- **Human Immunodeficiency Virus (HIV)** is a virus (pathogen) that causes an infection that may develop into AIDS in the later stages. **AIDS** stands for **Acquired Immune Deficiency Syndrome**. It is the most widely known STI caused by a virus.

Chapter 18: Inheritance

- **Hereditary traits** are traits or characteristics that can be passed on from one generation to another.
- **Inheritance** is the transmission of traits from one generation to another.
- A **gene** is a sequence of DNA nucleotides that controls the formation of a single polypeptide. It is also a unit of inheritance.
- **Alleles** are the different forms of the same gene. Alleles occupy the same relative position on a pair of homologous chromosomes.
- If a person has two different alleles, the allele that is expressed is called the **dominant allele**, while the other allele that is not expressed is called the **recessive allele**.
- The combination of alleles for a particular gene is called **genotype**.
- The expressed trait or outward appearance is called **phenotype**.
- **Homozygous** refers to having two identical alleles of a particular gene (e.g. DD or dd). An organism that is **homozygous dominant** for a certain trait or gene has two dominant alleles for the gene (e.g. TT). An organism that is **homozygous recessive** for a certain trait or gene has two recessive alleles for the gene (e.g. tt).
- **Heterozygous** refers to having two different alleles of a particular gene (e.g. Dd).
- An organism is pure-bred if it contains identical alleles. A pure-bred is a homozygous organism.
- A **test cross** is used to find out the genotype of an organism showing the dominant characteristic.
- In **codominance**, both alleles express themselves in the heterozygote, which has a phenotype intermediate between that of its pure-bred parents. The alleles are said to be **codominant**.
- A gene that exists in more than two different forms is said to have **multiple alleles**.
- **Variations** are differences in traits between individuals of the same species.

- Traits that are easily distinguishable and are not affected by environmental conditions show **discontinuous variation**.
- Traits with many intermediate forms show **continuous variation**. Continuous variation is brought about by the combined or additive effect of many genes.
- **Mutation** is a change in the sequence of a gene or in the chromosome number.
- **Gene mutation** occurs when there is a change in the base sequence of the DNA. It produces variation between individuals as it results in new alleles of genes. Examples of conditions caused by gene mutation are sickle cell anaemia and albinism.
- **Chromosome mutation** occurs when there is a change in the number of chromosomes in an organism. An example of a condition caused by chromosome mutation is Down syndrome.
- **Natural selection** is a process where organisms with desirable genes and characteristics are 'selected or favoured' to survive and pass on their genes to their offspring.
- **Evolution** is the gradual change in the inheritable characteristics of a population over time.

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